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SOCIETY FOR ENVIRONMENTAL GEOCHEMISTRY AND HEALTH

"LEAD IN SOIL" TASK FORCE

RECOMMENDED GUIDELINES

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EXECUTIVE SUMMARY

The lack of well founded guidelines in the United States and other countries for lead in soil, coupled with the confusion over exposure to lead, a special task force was formed by the Society for Environmental Geochemistry and Health (SEGH) to develop a report on recommended guidelines for lead in soil. The fourteen member task force is composed of SEGH members representing a balance between the regulatory agencies, industries, medical and public health profession and recognized researchers from the scientific community concerned with lead in soil.

In an attempt to make the report user friendly the opening section presents a simplistic outline of how to use this report. Emphasis is placed on the logical sequence to be followed as set forth in a "Phased Action Plan" and an "Appropriate Target Blood Lead Criteria" which has been developed into a management strategy for lead in soil. The rationale for each module in the decision matrix is outlined and explained (with documentation) in the Phased Action Plan section.

A formula has been derived for the selection of the appropriate target blood lead criteria (TBL which will then trigger the decision process as well as govern the cost of necessary remedial actions. Various levels of target blood lead criteria are used to illustrate how the TBL may be applied to the PAP to determine guidelines for site specific situations. The detailed rationale for this model is discussed and illustrated with examples.

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The Health section of the report has focused on population groups at risk for adverse health effects of lead.

Studies in many parts of the world, particularly those conducted during the past 15 years, have clearly identified the fetus and young child as the population groups at greatest risk for adverse health effects of lead. Because lead freely crosses the placenta, women of child-bearing age, as surrogates for the fetus, have also been identified as a high risk population group. Small but statistically significant increases in blood pressure have been found in middle-aged white males, as well as a small but significant increase in PbB in post-menopausal women; however, these last two groups are not considered to be at risk due to exposure to lead in soil. With regard to fetal exposure, recent studies show a significant reduction in gestational age that is inversely related to cord and maternal PbB levels. Some, but not all, studies have also shown a modest reduction in birth weight at blood lead levels > 12-13 µg/dl. Infants born with PbB > than 10 µg Pb/dl have shown impaired mental development at lease until two years of age. Several cross-sectional studies in children at 6 or 7 years of age have shown a significant reduction in verbal IQ scores, and furthermore, the verbal IQ scores remain normally distributed, so that the IQ of an overexposed population is shifted downward throughout the range, thereby reducing the number of children of superior intelligence and increasing the number of children classified as mentally retarded. In these studies, dentine lead in shed deciduous teeth has served as the marker of a chronic cumulative dose of lead

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during the early school years. One of these studies, in which children were reevaluated at 18 years of age, indicated that those with the higher dentine lead levels were 7.4 times more likely to have dropped out of high school, and 5.8 times more likely to have a reading disability as young adults, as compared with those with low dentine lead levels. The data, both in children and experimental animals, are consistent in indicating that the subtle, neurobehavioral adverse effects manifested primarily by learning disabilities are long-lasting, and very likely to be permanent.

The primary target organs for lead are the central and peripheral nervous system, the hematopoietic system, and the kidney. As recently as a decade ago, the hematopoietic system was considered the critical organ, or the one most sensitive to the adverse effects of lead. Recent studies have revealed that the developing nervous system is just as sensitive as the hematopoietic system, if not more sensitive. The developing nervous system is now classified as the critical organ, primarily because the adverse effects of lead on the nervous system do not appear to be reversible, while those on the hematopoietic system clearly are reversible. Significant adverse effects of lead on the kidney are found only at higher levels in relation to prolonged exposure. At the present time, at least in children, significant, long-lasting adverse effects of lead on the kidney have not been found.

The endogenous factors which effect the susceptibility of the fetus and young child to appear to be two-fold: 1) the young organism absorbs dietary lead from the intestinal tract at a much higher rate than does the adult. In the adult, approximately 10% of dietary lead is absorbed, very little of which is retained. By contrast, metabolic balance studies in infants show that about 50% of dietary lead is absorbed. When the dietary lead intake exceeds 5 µg/Kg of body weight per day, the infant is in positive lead balance. Studies in adults have indicated that the absorption of lead is increased by a factor of 3-5 when lead is administered in the fasting state. It would be unethical to conduct such studies in children. These factors, together with the very rapid growth rate, particularly of the neural system in infancy and early childhood, combine to render the child and fetus the population group at highest risk for overexposure to lead and its adverse effects.

Infants and children from birth to 6-7 years of age constitute the group at greatest risk for exposure to lead in soil. Within this overall age group, children between 6 and 36 months of age are perhaps the sub-group at highest risk. This is primarily because of developmental and behavioral considerations. It is in this age group that hand-to-mouth activity, including the mouthing and/or ingestion of non-food items, is considered a part of normal development and one of the means by which the infant and young child explore their environment. Between 6 and 12 months of age, infants begin to scoot, crawl and walk, thereby enabling them to move freely about the home, during which time they become more highly exposed to lead in interior household dust. Later on, perhaps at 4-6 year of age, they begin to go

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outside and so become exposed directly to soil. In all groups, a portion of the interior household dust represents lead from exterior soil which has been tacked in to the home, as well as blown in through open windows and doors. Infants and toddlers receiving inadequate social and physical stimulation may indulge in a greater amount of hand-to-mouth activity than those similarly exposed to lead in dust and soil but for some the quality of care-giving is higher. General cleanliness of the home also has been shown to influence PBB levels in children. This is particularly important for children under 3 years of age, who spend perhaps 80-90% of their time inside the house.

Measurement of the concentration of lead in whole blood provides an indicator of the internal dose of lead, and in epidemiologic surveys has served as the most widely used indicator of lead absorption for the past 20-30 years. The total amount of lead in whole blood at any point in time is the sum of both recently absorbed lead and lead absorbed in the past. Lead can and has been measured in urine and hair; however, such measurements in children are of no value for epidemiologic purposes. The definition of acceptable blood lead concentration has changed substantially during the past half-century. Historically, acceptable blood lead concentration has been defined as that concentration below which adverse health effects, as perceived at the time, were not likely to occur. For example, as recently as 1960 ? Pb/dl whole blood was considered the upper limit of normal in children. This was passed upon the observation that acute clinical manifestations and changes by x-ray in the long bones were not likely to be seen at lower levels. By the 1970's, it was noted that the blood lead threshold for increasing urinary output of coproporphyrin and delta aminolevulinic acid (substances which are increased in lead poisoning) was at the blood lead concentration of approximately 40 µg Pb/dl whole blood. The Surgeon General of the United States at that time recommended that the upper limit of normal blood lead concentration be lowered to 40 µg Pb/dl whole blood. The critical effect concept, as described in the report of the Subcommitte on the Toxicology of Metals of the Permanent Commission and International Association of Occupational Health, provided the scientific rationale and practical approach for the prevention of lead toxicity. Under this concept, if the critical or earliest measurable adverse effect could be identified and effective action taken, then later and more serious effects could be prevented. At the time this report was issued in 1976, the developing erythroblast in the bone marrow was considered the cell most sensitive to lead. More recent studies indicate that the developing nervous system is at least as sensitive, if not more sensitive, than heme synthesis in the bone marrow. Furthermore, the adverse neurodevelopmental effects of lead appear to be permanent, so that this is now considered the critical effect of lead. Recent studies indicate that the threshold for adverse health effects on the developing nervous system lies at the blood lead concentration of 10 to no higher than 15 µg Pb/dl whole blood. It is anticipated in the United States that the responsible government agencies will re-define the upper limit of acceptable blood lead concentration at a lower level of 10-15 μg Pb/dl whole blood.

Lead is a multi-media substance. When any survey is undertaken to evaluate exposure to lead in soil, other potential sources of lead for a particular population must be taken into account. In the United States, there have been substantial reductions in lead in air and food, which have been associated with substantial reductions in blood lead concentration. A similar natural lowering of blood lead concentration has also been noted in the United Kingdom. It is now generally considered that the major sources of lead for children are lead in soil, household dust, and paint. In some areas, where drinking water is "plumbosolvent" and "aggressive", drinking water lead may be a significant source. There are a number of sources, such as cottage industries and hobbies involving the making of pottery, other ceramic ware and art glasswork, that lead to gross overexposure within such homes. In some ethnic groups, folk medicines have been a cause of serious lead poisoning. In the United States at least, lead based paint ingested repeatedly by children has lead to clinical poisoning, including fatalities.

Bioavailability is discussed in regard to the amount of lead in a diet that may be absorbed into the blood stream. Factors that may influence whether lead in soil and dust ingested by children is absorbed into the blood include the physical and chemical properties of the particles, and nutritional status of the children. Another important consideration is the effect of increasing soil dose on lead absorption.

Lead absorption studies in children and adults have contributed to a better understanding of human lead absorption. Larger lead particles were found to have a lower toxicity than small particles or other compounds. The implications of these findings are that larger lead particles dispersed by mining would be expected to have a significantly lower bioavailability than other soil lead.

Iron deficiency was found to strongly affect lead absorption and an important finding was that lead absorption is greatly reduced by simultaneous ingestion of food. There was also a clear interaction between dietary calcium and phosphorus in animal and human studies.

Bioavailability studies of lead in soil and dust indicated that the chemical form and larger particle size of mining wastes was a possible reason for the reduced impact of lead sulfide in contaminated soils.

Stomach pH was evaluated as a factor in lead absorption and it was found that food and soil can buffer the pH of the stomach to levels around 6 which greatly reduces the dissolution of environmental or soil lead.

A section on risk management focused on the exposure assessment and development of a relationship between blood lead levels and the levels of lead in soil as a possible source of exposure. Blood lead levels were found to be impacted by exposure to other sources in water, food, paint and others.

Overall risk assessment was suggested on a site specific basis concerned with economic, legal, political and social

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factors. Risk communication is presented as a new policy focused on the different perceptions between the scientific and lay public concerning risk.

Uncertainties and non-technical considerations that must be used by the risk manager include the number and age of the population, present and future land use, and social-economic status of area residents.

Key factors associated with understanding the geographic distribution of lead in soil include rural background lead levels and contributions from aerosol sources of lead associated with 1) point, 2) linear, and 3) area sources. Patterns of lead were found to be complex but it was felt that soil lead and blood lead were related.

Legal aspects of lead in soil were examined in regard to the levels associated with the clean water, clean air and other standards. It was noted that the EPA has not established a reference dose nor set an acceptable daily intake level for lead. This inconsistency has prompted the EPA's Office of Solid Waste and Emergency Response (OSWER) to advise the regions to use the Centers for Disease Control (CDC) guidance of 500 to 1000 ppm for lead clean-up decisions.

Liability was examined in regard to the risk of having a person injured at a "cleaned-up" lead contaminated site. It was noted that the government or parties responsible for clean-up (or contamination) of the site would become the most likely target.

Economic considerations in establishing lead levels were evaluated on a cost-benefit analysis made on a case-by-case basis. Financial resources need to be determined before a remedial plan is established.

Remedial actions to treat soil were examined for soil 1) removal, 2) containment, 3) contaminant extraction, 4) deep tilling and 5) revegetation, barriers or zoning. The cost of no action was also examined in regard to detrimental impacts of lead exposure on populations at risk.

Suggested methods for soil sampling and analysis are to be found in the report supplements. The protocol and examples given should be of applied value in experimental design and sampling to determine soil lead levels.

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I. HOW TO USE THIS REPORT

The purpose of this report is to put a user friendly working document into the hands of public health officials, regulatory agencies, industrial environmental managers and others concerned with the question of how to determine if they have potential health problems with lead in soil. As a useful working outline, the report has been divided into sections that start with an introduction as to why the report was developed. The introduction is then followed by a section containing definitions used in the report to assist the reader in understanding the meaning of specialized terms used.

The report then presents a protocol or logic format which may be used in a step wise progression through six major areas as shown in Figure 1 and entitled as the Phased Action Plan. The first series of determinations concentrate on assessing if there is a Problem with lead in soil as indicated through steps A through D:

1. Unplanned elevated soil lead samples which may indicate a problem in the specific area being sampled (Step A).
2. Unplanned elevated blood lead (PbB) values which might arise from clinical investigations (Step B).
3. Unplanned discovery of lead in animal or plant tissues or indications of lead toxicity in domestic animals or wildlife (Step C).
4. Anticipated potential lead in soil problems on land that was previously used for industrial use and would be suspect in regard to lead contamination (Step D).

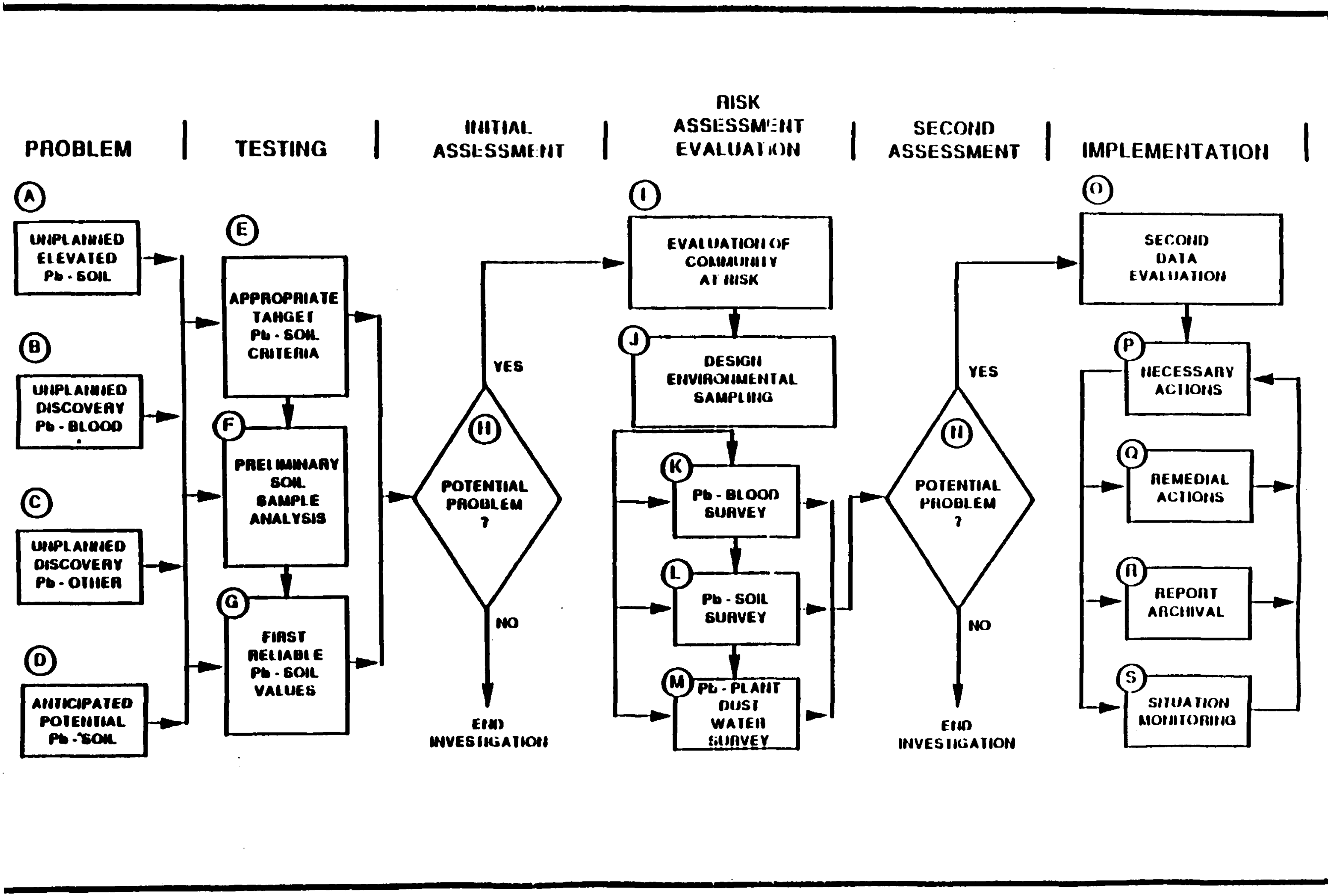

Figure 1. Phased action plan for lead in soil

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If any of these problems are found to be present, then the protocol moves to the second area entitled Testing which requires the use of:

1. A Soil/dust guideline based on blood lead guidelines. The relationship used is derived as explained in Figure 2 along with a series of examples and rationale which are discussed in detail in the health section of the report (Step E).
2. Preliminary soil sampling and analysis must then be carried out to characterize soil lead levels in the area under investigation. Recommended methods for soil sampling and analysis are to be found in the back of the report as a supplemental section concerned with this subject (Step F).
3. First reliable soil lead values may then obtained from the preliminary soil sampling and analysis which allows one to characterize the area for the next level of the decision making process (Step G).

The third area in the action plan requires an initial assessment of the Potential Problem based on the data obtained and target levels chosen and a decision made to either end the investigation or proceed to the Risk Assessment Evaluation area (Step H).

The risk assessment evaluation contains a series of steps to be made consisting of:

1. Evaluation of the community at risk to determine factors such as the number and age of the population at risk, land use and comprehensive sampling, to list a few. The supplemental section of the report may again be used

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concerning detailed sampling and analytical methods appropriate for use on a site specific basis (Step I).

2. Design environmental sampling to provide a general description of the project including necessary details associated with time tables and tasks, use of data, project organization and responsible individuals (Step J).

3. A blood survey would then need to be designed and performed by appropriate medical personnel utilizing a laboratory with an acceptable quality control program (Step K).

4. A soil lead survey would need to be made for those areas indicated by the risk assessment and environmental design. Details on sampling and analysis are again to be found in the special supplemental sections of the report dealing with sampling methods (Step 1).

5. Surveys of lead in dust, vegetation and water also to be conducted by methods as illustrated in the supplemental sampling and analysis section of the report (Step M).

The Second Assessment decision is then based on the evaluation of information gained during the risk assessment evaluation. At this time a decision must again be made on either to end the investigation or to proceed to the implementation (risk management) stage (Step N).

The implementation process requires the consideration of:

1. A second data evaluation now need to be considered in terms of financial resources available for the various actions to be taken (Step O).

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2. Necessary actions as addressed through a site specific risk management decision process. Details concerning how to develop a risk management strategy are noted in the section of the report dealing with this subject (Step P)

3. Remedial actions, if prescribed, must then consider a number of issues which are further described in the risk management section of the report (Step Q).

4. Report archival notes the requirement that all data collected and evaluated should be retained in an appropriate location for possible future use as necessary (Step R).

5. Situation monitoring requires that the site continue to be monitored in a planned fashion to determine the effect of clean up actions (Step 5).

Further details on the various steps as described in this format are to be found in the Phased Action Plan section of the report.

The Health section of the report details concerns of the population groups at risk, definitions of acceptable blood lead concentrations, discussions on other sources of lead and evaluations of appropriate case studies that may serve as an example. The use of health criteria in deriving the target soil/dust lead guideline concentration model should be carefully examined since this is the model used to determine the appropriate target foil lead/blood lead action level in the Phased Action Plan. Since a single number is questionable the examples given will help in understanding how the model and number range derived may be applied to different situations.

The bioavailability of lead has now become a major area of concern evaluating the impact of lead in regard to human health. The section concerned with this subject describes the factors that influence the bioavailability of lead in regard to chemical composition, particle size and other nutritional factors.

Descriptive information relating to the overall analysis of risk as associated with the suggested soil lead guidance is presented in the risk management section of the report. Possible remedial actions and associated cost considerations will be of interest to anyone concerned with implementing necessary actions to protect human health.

Recommended methods presently in use for soil sampling and analysis are presented in the report as supplements. These methods and sampling designs should be of applied value for use in various site specific evaluations that require quality control and the use of soil data for further evaluation and use in the Phased Action Plan matrix.

It is hoped that this report will be of applied value to decision makers concerned with lead in soil.

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II. INTRODUCTION

There is a lack of well founded guidelines in the United States and other countries for evaluating concentrations of lead in soil in terms of a possible impact on human health. This has contributed to confusion among regulatory agencies, industries, public health officials, the medical community and citizens concerned with evaluating or remedying lead contaminated soils. Public health officials and the medical community are expected to judge the health effects and risks from lead exposure. They must also decide the soil lead concentration that should be used as a basis for requiring remedial action at contaminated or hazardous waste sites. There is a clear need for better founded guidelines and this was emphasized in a special session of the 1987 Trace Substances in Environmental Health Conference held in Columbia, Missouri, U.S.A. following a key note presentation on "Lead in Soil: How Clean is Clean?" by Davies and Wixson (1986). As a result of the questions raised and the continuing urgent concern expressed, a special conference focusing on "Lead in Soil: Issues and Guidelines" was held in Chapel Hill, North Carolina in March 1988. Cooperating sponsorship was provided by the Society for Environmental Geochemistry and Health (SEGH), the United States Environmental Protection Agency (EPA), the International Lead Zinc Research Organization (ILZRO), the Lead Industries Association (LIA) and Clemson University, South Carolina. Over thirty scientific papers were presented to summarize pertinent scientific data, to examine previous and on-going lead in soil

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case studies and to evaluate guidelines or scientific approaches used in countries throughout the world. The conference featured panel and audience discussion on suggestions for possible approaches to be used in the development of U. S. guidelines for lead in soil. A "phased-action plan" approach was proposed by Wixson (1988) and accepted by the participants together with a request that a Society for Environmental Geochemistry and Health (SEGH) task force be formed to evaluate further the conference findings and to develop a report that would recommend guidelines for lead in soil based on a critical selection of the best available scientific data and knowledge. Papers presented at this special conference have been published by the SEGH Journal "Environmental Geochemistry and Health" as a special proceedings entitled "Lead in Soil: Issues and Guidelines", edited by Davies and Wixson (1988).

In June 1988, a status report entitled "Lead in Soil: Issues and Guidelines Conference Summary" was presented by Wixson (1989) at the Trace Substances in Environmental Health Conference held in St Louis, Missouri. A special task force was then approved to study and report on lead in soil under the auspices of the SEGH.

The "Lead in Soil" task force is composed of SEGH members and represents a balance of established and reputable scientists from regulatory agencies, industries, the medical profession, public health authorities and universities: all are active workers in this subject. The SEGH task force has been supported by the U.S. Environmental Protection Agency (EPA), International

Lead Zinc Research Organization (ILZRO), the Lead Industries Association (LIA) and Clemson University. Its remit is to develop a report utilizing a flexible matrix approach or "phased action plan" to evaluate the evidence and problems in its interpretation and, hence, to make recommendations for guidelines to appraise lead concentrations in soil.

The SEGH task force has held meetings and developed a protocol which is supported by scientific documentation. A "phased-action plan" was coupled with target soil lead concentrations derived through a model relating blood lead and soil lead concentrations. Such a plan allows for the combined influences of soil and other sources of lead on blood. Thus the model offers flexibility for the user to select appropriate target levels of blood lead concentrations while allowing for a variety of environmental situations or regulatory criteria.

The report lists pertinent definitions and presents a logical and easy-to-follow management strategy in the "Phased-Action-Plan" which is then coupled with the derivation of the "Appropriate Target Soil Lead Criteria" necessary for the decision making process.

The rationale for the Phased Action Plan and selection of the appropriate target soil lead criteria are then further explained following the step-wise logic used in the management strategy. Detailed summaries of the scientific data used in the various steps of the protocol are then presented and cited with examples of standardized sampling procedures provided in the soil sampling supplement.

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The report then summarizes the protocol development and applications of the Phased Action Plan and Appropriate Target Blood-Lead Criteria with an extensive explanation and documentation of literature used to support the factors affecting health and contributing to the development of a model.

The question of bioavailability is considered followed by a section on risk assessment which goes into more specific details.

The support given by agencies, industries, the SEGH and external reviewers is acknowledged. References to documentation used in supporting the development of the recommended guidelines for lead in soil is noted followed by supplemental sections on soil sampling and risk assessment.

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III. DEFINITIONS

Scientists use some words and terms in a very specialized and closely defined manner. Sometimes these words are used in everyday speech but with a wider or looser meaning. Also, words have been invented to provide for a specific communication need. The following glossary of such words is provided for the reader of this report.

BACKGROUND LEAD CONCENTRATION: the concentration of lead in soil at sufficient distances from known mobile or point sources of contamination such that it is representative of typical soils for the region in question.

BIOAVAILABILTY: for a given substance, different physical/chemical forms have different availabilities to, and therefore different effects upon, living organisms. Rarely is all the substance that is ingested or otherwise taken into an organism, absorbed by the organism. This means that a value for 'total' lead in a real environmental sample is almost always an overestimate of the amount of lead that is available and that will be absorbed. However, in the absence of reliable information concerning the form of lead in a sample, one should assume 100% availability. Moreover, at the present time only total lead can be determined accurately and precisely.

For scientific purposes, lead acetate, a water soluble lead salt, is used as the standard for 100% availability of dietary lead. When equal amounts of soil lead, or large particle lead sulphide, are added to the same test diet, the absorbed lead is lower than that of lead acetate, i.e., lower than 100%. This is due to the physical and chemical properties of these lead sources. The standard diet for bioavailabilty is a casein-sucrose (AIN 78) purified diet, because high fibre or phytate in diets significantly lowers the fraction of dietary lead that is absorbed.

CONTAMINATION: Soils which are formed on similar parent materials and which have similar arrangements of horizons, i.e., they have formed under similar environmental conditions and are of similar age, are grouped together by pedologists in a soil "series." There is evidence to suggest that the trace element concentrations, including lead, for a large number of samples of a given soil series in the natural state can be described as having an upper and lower limit on the concentrations. The frequency distribution of lead values from a large number of samples is usually positively skewed but this skewness can be minimised, i.e. the population normalised, by transforming the values to their $\log_{10}$ equivalents. The (geometric) mean value and the 95% or 99% probability ranges can then be calculated. Values for other samples apparently from the same series that do not lie within the range are described as anomalous and form a geochemical anomaly. If, from other evidence, it is deduced that the anomaly has been caused by anthropogenic activity, the geochemical anomaly becomes a neoanomaly and the soil is regarded as contaminated. Thus, a contaminated soil is one having a lead content larger than that expected from the pedological nature of the soil.

In practice, it may not be possible to identify a suite of uncontaminated soils. Statistical techniques exist for extracting the basal population. But this population is better described as 'background' rather than natural, uncontaminated.

DIRT: An ill-defined word which includes soil and dust and should not be used.

DUST: Loose mineral material lying as a thin veneer on a solid support. It is differentiated from soil in that soil is presumed to have formed from its rock base whereas dust has settled on the base. Dusts should be described as street, curb-side, settled-house or air-borne.

GARDENS OR YARDS: Excluding back-to-back terraced houses in industrial England most houses have associated with and adjacent to them a patch of open ground. In Great Britain part or all of this may be paved at the rear and is called the 'back yard' or when at the front, the 'forecourt'. Unpaved areas are used for growing grass (lawn), decorative plants or vegetables. All these unpaved areas are called 'garden'. In North America open areas are generally described as 'yard' and 'garden' will ordinarily imply a vegetable or flower plot.

LITTER: grass, dead leaves, decaying leaves, on the surface of a yard (garden) soil.

NEIGHBOURHOOD: a group of homes having similar external appearances and normally residents with similar socio-economic status, extending over an area of 16 - 25 square blocks (0.5 - 1 square mile), or equivalent to a US census tract.

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<u>PICA</u>: An abnormal craving for certain unnatural foods such as clay, chalf, soil, paint chips or other materials.

<u>POLLUTION</u>: A term which has been expressed in many different ways. Wanielsta, et. al. (1984) have described pollution as "that which modifies the environment such that its use is affected." Warren (1971) devotes a chapter in his book for a discussion on pollution as a word that has social significance and is much used by individuals or groups to take on different meanings or stimulate legislation or appear in laws.

The report by the National Research Council Committee on Pollution (1966) starts off with "Pollution is an undesirable change in the physical, chemical, or biological characteristics of our air, land, and water that may or will harmfully affect human life or that of other desirable species, our industrial processes, living conditions, and cultural assets, or that may or will waste or deteriorate our raw material resources".

This means that a soil may be described as contaminated yet the concentration of lead in that soil may not be large enough to cause andy deleterious biological effects. But where the lead or concentration does rise to a value where a specific organism is adversely affected then the soil may be described as polluted. Since pollution is an anthropogenic process then a soil should not be described as polluted where the lead content has reached injurious levels through natural processes.

Based on these various explanations and adapting soil from the water usage terms of Warren (1971), this report sould simplistically define soil pollution as "any impairment of the

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suitability of soil for any of its actual or beneficial uses, by man-caused changes."

PROPERTY: In North America the word is used generally to describe the plot of land upon which a building is situated and belonging to that building through freehold or leasehold. The term is in use in Great Britain, but less widely, and may be restricted to the building.

QUALITY ASSESSMENT (QAS): the overall system of activities to provide assurance that the quality control task is being performed effectively. Quality assessment involves a continuing evaluation of performance of the production system and the products produced.

QUALITY ASSURANCE (QA): a system of activities, the purpose of which is to provide the producers and users of a product or service with the assurance that it meets defined standards of quality with a stated level of confidence. The QA system includes the separate but coordinated activities of Quality control and Quality assessment.

QUALITY CONTROL (QC): the overall system of activities designed to control the quality of a product or service so that it meets the needs of users.

SCHOOL YARD: the area adjacent to a school where children play.

SOIL: The loose and weathered veneer of material overlying and merging with rock. Agronomists restrict the meaning of soil to the weathered material in which plants grow and distinguish 'pedogenetic' processes from geological weathering. Engineers

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extend the term to all loose surface materials. The agronomic usage is adopted here.

Yard or Garden Soil: The soil found in gardens or yards. Surface soil is the top 2-6 inches (5-15cm) which contains the roots of most garden plants, while subsurface soil lies below 6" or 15cm. Litter includes grass, leaves etc. lying on the soil. Any surface litter accumulation is regarded as 'above surface material'.

Subsurface Yard or Garden Soil: The soil located in yards (gardens) at a depth of 2 - 6 inches below the litter level.

TRIGGER VALUE: the term used by the British Department of the Environment (Simms and Beckett, 1986) for concentration of lead in soil which, for the particular area and set of conditions under consideration, indicates the need to evaluate the risk to human health from the soil lead and, if necessary, leads to some kind of remedial action on or limitation of use of the land. There is no absolute value of lead in soil that can be used as a trigger.

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IV. PHASED ACTION PLAN

This chapter is concerned with the flow diagram of the phased action plan, shown in Figure 1. The details of the several steps involved in interpreting the plan are discussed in the Soil Sampling and Environmental Aspects supplements at the end of the report. Discussion here is restricted to a concise description of each step as noted in the sequence A to S contained in Figure 1.

Step A: Unplanned Discovery of Elevated Soil Lead.

This step is primarily concerned with the evaluation of and action resulting from lead data derived from a systematic sampling of soil. However, an analysis for lead may be carried out on any sample of soil as a result of an individual's curiosity or suspicion. This is therefore termed an unplanned discovery. Unplanned discoveries may also emerge from soil surveys carried out for other purposes. The analytical value from such a process cannot be accepted uncritically; it should therefore be regarded as a crude value.

Step B: Unplanned Discovery of Elevated Blood Lead.

Concern about lead in soils and dusts might initially be raised as the result of the accidental discovery of one or more elevated blood lead values which might arise from clinical investigations in the area in question. Any elevated blood lead found in this way must be confirmed by repeat sampling and analysis and evaluated with respect to the health criteria adopted for the particular population.

There has been a trend to both lower blood lead values in the general population and to lower standards for acceptable blood lead concentrations, so that any criteria adopted at one time and place may not be suitable for all situations. The background information to be considered when adopting the health criteria are discussed in the health section of the report.

If the circumstances of the individual(s) tested suggest that soils and dusts could be a factor contributing to their unacceptable blood lead concentrations, then consideration should be given to proceeding to Box G for obtaining the first reliable soil lead values.

Step C: Unplanned Discovery of Elevated Lead in Other Media.

This is the discovery of elevated lead in animal or plant tissues, or some indication of a lead toxicity problem in livestock, domestic animals or wildlife, which imply the possibility that soil lead might be involved in the cause of the raised lead value.

Step D: Identification of a Potential Lead in Soil Problem.

Situations can sometimes be identified where there are reasons to suspect soil lead problems exist. The suspicion may arise from considering the history of land use (a smelter once stood there, perhaps) or from recognizing conditions of lead toxicity or excessive accumulation in biota. The further use of such land would lead immediately to a preliminary soil sampling (Box F).

Step E: Appropriate Target Soil Lead Criteria

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Proposing a single value guideline for an upper concentration of lead in soil to protect young children was considered unrealistic for a number of reasons. Various blood lead concentrations are used as health standards around the world and these change as the health effects of lead are reinterpreted. The environment of the population at risk can vary widely. People may be exposed to lead in urban dusts derived from automotive emissions and leaded paints or to soil and dust contaminated by smelter emissions. Lead contamination is often widespread in old lead mining areas. Waste disposal sites can cause metal contamination locally. The population at risk can itself vary from situations where there is a high proportion of young children to a retirement home for the elderly.

Because of these considerations, the soil/dust 'guide line' is proposed as a relationship or formula. This allows adjustment for a variety of environmental situations and regulatory criteria. A number of recent papers have dis cussed modelling techniques applicable to multiple source exposure to lead and these are discussed in the Health section. Alternate models can of course be used within the framework of this document according to the data available and allowing for other priorities.

In the model we have developed, blood lead concentration is equated to a baseline level plus an increment resulting from exposure to soil or dust lead. The model takes account of the chosen blood lead guideline or target concentrations and the degree of protection required in the population. The slope of the blood lead - soil lead relationship used in calculating increase in blood lead over a baseline value, and hence the soil guideline, can vary depending on a variety of factors. Thus, the response can be adjusted for a given situation and modified as more data become available.

The relationship derived is as follows:

$$S = \frac{\left[\frac{T}{G^{n}} - B\right]}{\delta} \cdot 1000$$

where:

S is the soil or dust guideline, a geometric mean concentration in μg Pb per gram of dust (i.e., ppm)

T is the blood lead guideline or target concentration, in μg Pb/dl whole blood

G is the geometric standard deviation of the blood lead distribution, typically in the range of 1.3 to 1.5

n is the number of standard deviations corresponding to the degree of protection required for the population at risk, and would normally follow from the way in which the blood lead guideline T was defined; e.g. that 95% of the population should have blood lead concentrations less that 20 μg/dl. Parameter n can be obtained from standard statistical tables, and some representative values are given below for different percentages of the population desired to be below the target blood lead concentration.

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Percentage of Population < T	approximate value of n
50	0 (target is mean)
95	1.64
98	2.05
99	2.32
99.9	3.04

B is the background or baseline blood lead concentration in the population from sources other than soil and dust. Data from an appropriate control group would be ideal - a group matched not only for population characteristics, but also for similar lead exposure from all sources except soil and dust. If there are appreciable contributions from other sources such as smelter emissions or leaded paint, these must be measured or estimated for addition to the baseline value. If these data are not readily available, any proposed investigation should evaluate the contributions from other suspected sources.

δ (delta) is the slope or response of the blood lead - soil (dust) lead relationship and has the units of μg Pb/dl blood increase per 1000 ppm increment of soil or dust lead.

Step F: Preliminary Soil Sampling and Analysis.

The procedure for making the first (the preliminary) systematic soil sampling and analysis for lead will follow a decision to proceed from an unplanned discovery (Boxes A, B and C in Figure 1), or from knowledge that there is already a potential soil lead problem (Box D).

If preliminary soil sampling is required, it is necessary to delimit the 'neighborhood' and design an appropriate sampling and analysis protocol (including appropriate quality control procedures).

To evaluate the extent of a possible soil lead problem, the preliminary sampling is designed to characterize typical soil lead levels in a neighborhood, rather than for individual houses, or particular spot locations around a house. The preliminary soil sample will normally be taken from the back of the house, generally in the center of the open space behind the built structure.

In the preliminary sampling and analysis, as at all stages of the investigation, it is necessary to take precautions against contamination or bias of samples, and to prescribe and adhere to stringent quality assurance (QA) and quality control (QC).

<u>Step G: First Reliable Characterization of Soil Lead Values</u>.

From the values that are obtained from the preliminary soil sampling and analysis, a relatively simple statistical treatment of the data will result in the characterization of the area in terms of the 'First reliable soil lead value'. This is the value that is used for the next level of decision making (Box H in Figure 1).

<u>Step H: Potential Problem?</u>

At this point, the value for soil lead is evaluated in terms of a 'trigger' value, and a second decision point is reached. There is no absolute trigger value, but the soil lead information which is now available in the investigation, and upon which a decision can be made, is technically superior to that which was used to enter Box E. Based on the data obtained and the target levels chosen, the decision must be made either to end the investigation or to proceed to the risk assessment evaluation contained in the next step (Box I of Figure 1).

Step I: Evaluation of Community at Risk.

Evaluation is based on an exposure assessment and, in particular, the development of a relationship between blood lead concentrations and the contents of lead in soil where soil is considered to be one possible source of exposure.

The objective of this analysis is to propose a suggested guidance for the relationship between lead in soil and the results of blood lead levels. This relationship forms part of the exposure assessment. Other parts of the exposure assessment include contributions to blood lead from dust, water, food, paint and other sources.

Among the numerous technical and non-technical aspects that need to be considered are the number and age of the exposed population. If the area of concern contains children living in low income housing or areas frequented by children such as school yards or playgrounds, the pollution hazard is far more significant than if it contains commercial buildings such as factories or warehouses or if children are likely not to represent a significant proportion of the population, e.g., retirement communities.

The present and probable future land use needs to be considered in deciding whether and what kind of remedial effort

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is required. Overall risk assessment can be achieved on a site-specific or case-by-case basis. If the major exposure route is from the soil then the guidance suggested in this report may be used directly to determine clean up levels.

The nature of further sampling will depend upon the specific site and its set of conditions and, clearly, it may not be possible to sample all media. For example, in an area where development has not begun there will be no domestic plumbing from which drinking water supplies are derived and water analysis is not relevant. Nor can there be paint to scrape from existing structures. It may even be necessary to estimate the potential exposure to lead from other sources, since this stage leads to a risk analysis, for which other sources should be considered. Even though the purpose of the present procedure is to evaluate the impact of soil as a source of lead, judgment cannot be made without considering potentially confounding factors in as quantitative a manner as possible.

In contrast with the preliminary soil sampling (Box F), which is conducted without any measurement of the effect on the human population, this step will usually include a comprehensive sampling, including blood leads from most households that have children. It is therefore recommended that the appropriately comprehensive sampling of other media be carried out at the same time as the blood lead survey (if one is conducted). Soil, paint, dust and water should be sampled at every home that provides a blood sample. This avoids any nuisance that might arise from revisiting and intruding on the home. The decision can then be made later whether or not to analyze all these other samples for lead.

For the detailed sampling, lead should be determined as follows:

1. Blood lead in children 1 - 5 years of age.
2. Soil lead for surface yard or garden samples- subsurface yard or garden samples
3. House dust.
4. Interior paint.
5. Drinking water.
6. Street dust.
7. Air.

The detailed procedures for sampling soil, dust, paint and air are described in the supplemental sections of the report. The purpose of this second level of sampling is to characterize the soil lead more accurately and in more detail, as well as to evaluate other sources of lead.

Step J: Design of Environmental Sampling

The U.S. Environmental Protection Agency has outlined a number of items which must be considered for inclusion in a QA project plan (U.S. Environmental Protection Agency, 1979). Those pertinent to the collection of data include: (a) project description, organization, and responsibility, (b) QA objectives for the measurement of data in terms of precision, accuracy, completeness, representativeness and comparability, (c) sampling procedures and custody, (d) calibration procedures and frequency, (e) analytical procedures, (f) data reduction, validation and reporting, (g) internal and external quality control checks, (h) performance and systems audits, (i) specific routine procedures used to access data precision, accuracy and completeness, (j) corrective action, (k) QA reports to management. A brief description of these items is summarized below and detailed. Additional information can be obtained from supplemental materials at the end of this report.

The environmental sampling program should provide a general description of the project including experimental design. It can be brief but should be sufficiently detailed to allow those responsible for reviewing and approving the program to complete their task. It should include a timetable for the initiation and completion of tasks within the program, a statement of the purpose for which the project is planned, and the intended use of the data. The plan should show project organization and line authority. Individuals responsible for ensuring the collection of valid data and the for assessment of measurement systems for their precision and accuracy should be identified. A person responsible for carrying out the provisions of the QA plan, a QA officer/manager, should be appointed and identified. All project personnel with responsibility for the quality of the data should receive a copy of the QA project plan and be aware of its contents.

<u>Step K: Blood Survey</u>.

Any detailed blood survey must take account of several important considerations before it is initiated. The health criteria against which the survey results are to be judged should

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be agreed during the planning stages and procedures established for providing appropriate medical and environmental follow-up of any individuals whose blood lead content exceeds the projected guideline value. This would be necessary whatever the decision taken about any action concerning the area and population in question.

Blood samples should be taken by personnel properly trained to avoid sample contamination and using demonstrably low-lead materials. The blood should be analyzed only by a laboratory experienced in routine blood lead analysis and whose quality assurance program includes satisfactory performance in an external quality control scheme.

The individual results should be made available to the participants along with an interpretation of the survey findings. Any individuals suspected of being unduly affected must be referred to the appropriate physician or hospital for further investigations.

Step L: Soil Lead Survey.

For detailed soil sampling an extensive set of samples should be taken. These should represent the drip point of the overhang on each side of the house, the centroid of the front, if one exists, as well as a three point transect across the back yard (garden). In these cases, each sample will be analyzed separately rather after bulking together. This will provide more detailed information on the extent, location and source of the contamination. It is probable because of the shedding of paint from buildings and impaction of lead aerosols on buildings, that the absolute value of the samples taken from the sides of buildings will be higher than those collected in the preliminary soil sampling from the backyard.

For schoolyards, public playgrounds, parks or other amenity areas, the detailed soil sampling will utilize a grid sample in order to map the extent of the contamination. A sample should be taken from the intersection of each of the grid lines. For vacant and industrial areas or for agricultural land, the grid system should also be used. Again, the sample from each grid intersection must be analyzed separately although that sample may be made up of individual soil cores.

Detailed sampling programs containing illustrations on techniques, number and location of samples and other pertinent information are found in the supplemental section of the report.

Step M: Surveys of Lead in Dusts, Plants and Waters.

Sampling protocols for plant, dust, water and paint are covered in the supplemental materials on sampling.

Step N: Potential Problem?

Based on the evaluation of the information gained during the various steps of the risk assessment evaluation, the decision should be made either to end the investigation or to proceed to the Implementation Stage. This starts with Step O and is concerned with a second data evaluation.

Step O: Second Data Evaluation

Before deciding the nature and scope of any remedial action it is important to ascertain the availability of financial resources. Depending on the specific site location, size and

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uses, the contaminated site may be eligible for public sector assistance (e.g., community, state and federal resources) which may supplement any private sector funds. Without this inventory of resource availability inadequate or inappropriate remedial actions may be proposed.

The costs involved with the physical cleanup of the soil are not always the only ones incurred during remedial actions. Legal liabilities may be created through either taking or not taking action. These play a significant role in determining the scope of the remedial action plan. The costs of monitoring a site after the cleanup has been completed should also be included when estimating the total cost of remedial action.

Step P: Necessary Actions

Based on the findings of the second data evaluation made in Step O, a risk assessment/management plan for the specific site needs to be considered. Factors involved in the risk management decision process include economic, legal, political and social aspects. The uncertainties and non-technical issues concerned with the risk assessment and management are presented in the supplemental materials at the end of the report.

Step Q: Remedial Actions

If the risk assessment/management plan prescribes remedial actions then a number of issues must be considered. These include economic and financial considerations, legal and liabilities involved in taking or not taking action; various types of soil treatment to reduce potential health risks, community education and behavior modification. More specific information on these issues and recommendations for cost effective methods are contained in the section on risk management and remedial actions.

Step R: Report Archival

All data collected and evaluations made throughout the various steps of the phased action plan for lead in soil need to be retained in an appropriate public domain archive (e.g., the appropriate agency office designated by federal or state law in the USA or more generally in a library or computer data base). The reports should be available for review or use if there is a change in the usage of a specific site or the population at risk.

If for any reason it becomes necessary to continue additional evaluations of a site then the data collected, evaluated and decisions reached earlier will serve as a base for the later assessments with a consequent saving in time and money. It is therefore imperative that good records be maintained for possible future use.

Step S: Situation Monitoring

After remedial action has been completed, the site must be monitored by a purposeful plan to ensure that the cleanup actions remain effective. The scale, duration, cost of monitoring and record keeping depends on the type of action taken and should be included in the project budget. Finally, after a further passage of time, the action should again be evaluated and recorded for future reference.

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V. HEALTH

In this section the factors concerned with lead and health are discussed in terms of the population groups at risk and in terms of adverse health effects of lead. The resulting health criteria are then used to derive a target soil or dust lead guideline concentration.

A. Population Groups at Risk for Adverse Health Effects of Lead.

Exposure to lead and its adverse health effects have been intensively studied, particularly during the past 15 years. These studies, which have been reviewed and critically evaluated in the Air Quality Criteria for Lead (US EPA, 1986), have identified the fetus and young child as the population groups at greatest risk for adverse health effects of lead. Because lead freely crosses the placenta, women of childbearing age, as surrogates for the fetus, are also identified as a high risk population group. In addition, analyses of the NHANES-II data (Mahaffey et al, 1982) suggest that: 1) modest increase in blood lead concentration (PbB) in middle-aged white males may be associated with a very small but statistically significant increase in blood pressure and, 2) may be associated with a 25% increase in PbB in post-menopausal women. One should note the data suggest that in post-menopausal women the effect is greatest in nulliparous women and least in multiparous women. These latter groups are not considered at risk for over exposure to lead in soil.

1. Fetus.

Paul (1860) was the first to report an increased incidence of spontaneous abortion and stillbirth in pregnant women with clinical manifestations of severe lead poisoning. This observation was confirmed by others during the next 50 years and led to the recommendation that women be excluded from the lead trades, a recommendation that has been accepted in many countries. Tissue analysis of the products of conception (Barltrop, 1969) reveal that lead freely crosses the placenta and accumulates in the tissues of the fetus at a high rate during the third trimester of pregnancy. The concentrations of Pb in the various tissues of full term stillbirths were found to be equivalent to those reported in non pregnant adult females (Barry, 1975). A number of studies have shown that maternal PbB and infant cord PbB are essentially equivalent at birth.

A number of prospective studies on lead absorption and its health effects are now in progress in the United States, the United Kingdom, Australia, Yugoslavia, and Mexico. In these studies women are enrolled during pregnancy and their offspring are to be followed longitudinally at least until school age. These studies are notable for the numerous covariates and potentially confounding variables that have been taken into account in the analyses of the data. The studies in Boston and Cincinnati in the United States and in Port Pirie, South Australia, are the most advanced at the present time. The findings, summarised by Davis and Svendsgaard (1987), show a significant reduction in gestational age that is inversely related to cord or maternal PbB levels. This has been a consistent finding in most of the studies. Some, but not all, studies have shown a reduction in birth weight at blood lead levels greater than 12-13 µg/dl.

The Boston study (Bellinger et al, 1987) is concerned primarily with prenatal exposure to lead, inasmuch as average PbB postnatally in this upper middle class cohort of infants was 5-7 µg Pb/dl. At birth, however, these investigators divided infants into 3 prenatal lead exposure groups: low (PbB 0-3 µg/dl); mid (PbB 5-8 µg Pb/dl); and high (PbB 10-18 µg Pb/dl). These investigators have reported that infants born with PbB greater than 10 µg/dl show impaired mental development at least until 2 years of age (as indicated by the Bayley Mental Developmental Index). After correction for covariates and confounders, mean IQ differed by 7 points between the low and high cord blood lead groups.

2. <u>Child: Birth to 6 or 7 Years</u>.

Byers and Lord (1943) were the first to report that clinically acute lead poisoning during early childhood had lasting neurotoxic sequelae. Nineteen of the twenty children whom they followed through the early school years were excluded from school. They attributed this primarily to anti-social behavioural disorders, short attention span and sensorimotor deficits. They remarked upon the fact that these children failed in school despite the fact that they had apparently normal intelligence quotients (IQ) as judged by global intelligence test scores. By the early 1970s (Lin-Fu, 1973), emphasis began to change from treatment to prevention and to the study of the

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effects of low level lead exposure in asymptomatic children. The work of Needleman et al (1979) found, in a general population cross-sectional study of first and second grade school children, a significant 4 point reduction in verbal IQ, shortened attention span and a dose related increase in the frequency of unfavorable classroom behaviors. A recent follow-up evaluation of this cohort (Needleman et al, 1990) suggests that these early developmental effects are reflected in later high school performance and academic success. A number of other cross-sectional studies have been reported since 1979, and are reviewed in detail elsewhere (US EPA, 1986; Smith, Grant and Sors, 1989). Some have confirmed the findings of Needleman and his group, while others have failed to find statistically significant differences. A number of the studies, including those of Needleman, have been criticized on the basis that the number of subjects in each group were too small to achieve adequate statistical power or that the studies failed to control for important confounding factors.

The limitations of cross-sectional studies have led to the several prospective longitudinal studies now in progress. It should first be noted that the lead exposures as indexed by PbB levels have decreased substantially during the past 30 to 40 years, particularly during the past decade. Thus, the current, ongoing prospective studies are being carried out with children with substantially lower PbB's than those encountered in the United States in the general population during the 1970's. The reductions in exposure to lead appear primarily due to reductions of lead in food, water, and air. The prospective Boston study, (Bellinger et al, 1989) has dealt primarily with prenatal exposure to lead while the other prospective studies have dealt with a combination of elevated pre and post natal exposure to lead. The Port Pirie study (the most advanced of these prospective studies), indicates that intelligence as measured at four years of age is inversely related to the integrated PbB concentration up to 3 years of age (McMichael et al, 1988). As integrated lifetime average PbB increased from 10 to 31 μg Pb/dl, the general cognitive index decreased by 15 points, 7.2 points of which were attributable to lead after correction for covariates and confounders.

While most of the prospective studies are reporting some lead-related developmental effects, the nature of the insults, and the exposure patterns with which they are associated, are not consistent across the studies. Furthermore, much remains to be learned regarding the relative importance of prenatal and postnatal exposure, the persistence of the effects and their long term impact on social and academic competency. The prospective studies are extensively reviewed elsewhere (US EPA, 1986; Davis and Svendsgaard, 1987; Smith, Grant, and Sors, 1989).

3. <u>Organ Sensitivity</u>.

The primary target organs for lead are the central and peripheral nervous system, the hematopoietic system and the kidney (US EPA, 1986). Effects on other organ systems have been reported, but occur only at very high levels of exposure. Lead has been shown to inhibit heme synthesis in every organ in which the question has been studied. Furthermore, each cell synthesises its own hemoproteins. The principal enzymes affected are porphobilinogen synthase (PBGS), formally known as delta-aminolevulinic acid dehydrase (ALAD) and ferrochelatase. These partial inhibitions are associated with a pathognomonic constellation of biochemical changes, including in vitro inhibition of PBGS activity in peripheral blood, increased zinc protoporphyrin in erythrocytes and increased outputs of delta-aminolevulinic acid (ALA) and coproporphyrin in urine in association with normal or slightly elevated outputs of porphobilinogen and uroporphyrin in urine. While the PbB threshold for inhibition of PBGS activity in vitro lies at a PbB of 5-10 μg Pb/dl or less (Chisolm et al, 1985), the blood lead threshold for increasing zinc protoporphyrin is at 15-18 μg Pb/dl (Piomelli et al, 1982; Hammond et al, 1985). The effects of lead on the biosynthesis of heme are reversible, including lead-induced anemia. Inhibition of heme synthesis in the developing erythrocyte in the bone marrow was identified as the critical or most sensitive adverse affect of lead (Nordberg, 1976). This established the scientific basis for the use of micro erythrocyte protoporphyrin tests for screening purposes. It should be noted that erythrocyte protoporphyrin levels are also increased in iron deficiency states. In the light of more recent data on the neurotoxic effects of lead, it would appear that the developing nervous system is at least as sensitive, if not more sensitive to lead, than heme synthesis in the bone marrow, an effect which is reversible. Furthermore, experimental

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data and studies in man strongly suggest that the neurotoxic effects of lead are not reversible. Various other metabolic and neurotoxic effects of lead as studied in experimental animals and man are beyond the scope of this text but are reviewed extensively elsewhere (US EPA, 1986).

4. <u>Endogenous Factors Affecting the Susceptibility of the Fetus and Young Child to Lead</u>.

Factors which render the fetus and young child more sensitive to lead than older children and adults relate primarily to the very rapid growth rate during this early period. Indeed, the nervous system has a growth rate more rapid than other tissues during the latter part of fetal development and early postnatal life up to about 6 years of age. The brain in infant experimental animals tends to accumulate and retain lead long after dosing with lead is stopped, a phenomenon not observed in mature animals. It has also been shown (Ziegler et al, 1978) that human infants from birth to 2 years of age absorb approximately 50% of dietary lead, one half of which is retained. By contrast, adults absorb 8-12% of dietary lead, only a very small fraction of which is retained. Indeed, the data of Ziegler et al (1978) indicate that an infant is in positive lead balance when the dietary intake of lead exceeds 5 μg Pb/kg body weight/day. Studies in human adult volunteers indicate that the absorption of lead is increased by a factor of 3 to 5 when administered in the fasting state. It should further be noted that infants receive a diet composed primarily of milk. In experimental animals milk has been shown to increase the absorption of lead. Cow's milk, unless fortified, is also deficient in iron and copper. The bioavailability of zinc may also be reduced in cow's milk. The experimental data in animals indicate that deficiencies of these elements enhance the absorption and retention of lead (Mahaffey, 1981). The demands of growth render infants and toddlers highly susceptible to nutritional deficiencies. In summary, very rapid growth rate, particularly of the neural system, and the high rate of intestinal absorption and retention of lead are the principal factors which make the fetus and young child the population group at highest risk for over exposure to lead and its adverse health effects.

B. Populations at Risk for Exposure to Lead in Soil

Infants and children, from birth to 6 or 7 years of age, constitute the group at greatest risk for exposure to lead in soil. Within this overall age range, children may be divided into two age groups; namely, 6-36 months of age and 37-72 months of age, based primarily upon developmental and behavioural considerations. Even so, it should not be forgotten that studies among older children living in proximity to stationary point sources of lead emissions, such as smelters, have also shown increases in PbB although the degree of increase has not been as great as it is in younger children similarly exposed (Landrigan et al, 1975; Yankel et al, 1977; Roels et al, 1980). The hand to mouth route of lead in soils and interior household dust has been well documented as a major pathway of environmental lead into the

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bodies of young children (Sayre et al, 1974; Roels et al, 1980; Bornschein et al, 1987).

1. Children 6-36 Months of Age.

Until approximately 6 months of age, infants tend to spend virtually all of their time in cribs (cots). Between 6 and 12 months of age, infants begin to scoot, crawl and walk, thereby enabling them to move freely about the home during which time they become more highly exposed to lead in interior household dust. A portion of this dust represents lead in exterior soil tracked into the home, as well as that which may be blown in through open windows and doors. During this age period, infants and toddlers tend to spend 80-90% of their time indoors.

The most important factor is the prevalence of hand to mouth activity as a normal developmental component of behaviour in this age range. Virtually all children suck their thumbs and fingers during their first year of life. Sucking fingers occurs as a result of the sucking reflex. Barltrop (1966) noted its occurrence at 12 months of age in 80% of children studied, as determined on the basis of 24 hours and 14 days recall by parents. After 12 months of age, thumb sucking and finger sucking tend to taper off slowly over the next five years, at the end of which, perhaps, only 20-30% of children are reported to show this activity. Between 12 and 72 months of age, thumb sucking generally occurs in relation to fatigue, boredom, illness, punishment and other frustrating situations to which the child responds by regressing to a more infantile type of behaviour. After 5-6 years of age, finger sucking should be

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considered as evidence of emotional immaturity (Harper and Richmond, 1977). Among older children, particularly males, playing in the dirt and a disregard for cleanliness go hand in hand. Thus, exposure to lead in soil can persist well into the school years. Indeed, the study of Roels et al (1980) was based primarily on older school-aged children and environmental data obtained by measuring lead in soil in school yards.

It is normal for a child to mouth foreign objects during infancy. If they ingest non-food items such as any item from the floor, dirt, plaster, wood, sand etc., the habit may be defined as "pica". During infancy, this represents oral exploration of the environment. Why children exhibit this habit is unknown, although dietary deficiency of iron has been proposed, but not substantiated. Lourie (1963) considered the "absence of mothering" as an important factor in the etiology of pica. "Absence of mothering" might be due to the fact that the mother was out at work, preoccupied with younger infants, mentally disturbed or an abuser of alcohol or other drugs. In the study of Barltrop (1966) pica or ingestion of non-food substances was observed to occur at about one-half the frequency of mouthing during the age period from 12-72 months. Some mentally deficient children may persist in the habit of pica throughout childhood and well into the adult years. In more recent studies on lead exposure in preschool age children the Caldwell HOME inventory has been used to assess the role of caregiving in the home on mental development. Several investigators have found that 3 subscales of the HOME in particular (Maternal Involvement with

Child, Provision of Appropriate Play Material, and Emotional and Verbal Responsivity of Mother) were negatively correlated with cumulative lead as indexed by serial PbB measurements. It was noted that even within the same socio-economic class wide variation in the quality of caregiving was found. These findings suggest that infants and toddlers receiving inadequate social and physical stimulation may indulge in greater amounts of hand to mouth activity than those similarly exposed to lead in dust and soil but for whom the quality of caregiving was higher (Schroeder, 1989). General cleanliness of the home also has been shown to influence PbB levels in children (Yankel et al, 1977).

2. Children 37-72 Months of Age

Between 3 and 6 years of age, the habits noted above persist but decrease in prevalence and frequency. Also, growth rate has decreased substantially. Conversely, children in this age range will tend to spend more time outdoors where they can be exposed directly to lead in soil in their play areas, particularly if their play areas are bare soil.

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C. Definitions of Acceptable Blood Lead Concentrations.

Measurement of the concentration of lead in whole blood provides an indicator of the internal dose of lead and has served in epidemiological surveys as the most widely used indicator of lead absorption for the past 20 to 30 years. The total amount of lead in whole blood at any point in time is the sum of both recently absorbed lead and lead absorbed in the past. For example, an isolated brief episode of sharply increased lead absorption will sharply elevate blood lead concentration for a short period of time. Lead is stored primarily in bone from which it is slowly recycled back to the blood over a long period of time. Despite these shortcomings, it remains the most useful index of lead exposure and absorption for the purposes of epidemiological surveys.

Lead can and has been measured in urine and hair. There may be wide variation in concentration of lead in urine so that urine lead measurements are not useful for epidemiological surveys. Lead may be adsorbed on hair so that a hair lead measurement does not necessarily represent what has been absorbed into the body and incorporated into the hair. This measurement is considered of no use for epidemiological purposes. The use of the calcium disodium EDTA mobilisation test for lead has been largely limited to clinical research. Furthermore, this test may not be without hazard inasmuch as experimental studies indicate that a single dose may elevate the concentration of lead in brain and liver (Cory-Slechta et al, 1987). Newer techniques for the measurement

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of lead in bone as well as the measurement of lead in shed deciduous teeth still fall within the realm of research.

The erythrocyte protoporphyrin (EP)* test is widely used in screening for increased lead absorption and toxicity in the United States. "Free" erythrocyte protoporphyrin (FEP) is also elevated in iron deficiency so that the test is not specific for lead. Serial measurements of lead and FEP over time are useful in following trends in lead absorption.

All the clinical data on the effects of lead on early neurodevelopment have used either blood lead concentration or the concentration of lead in shed deciduous teeth as the index of the lead dose. Although the need for a soil lead survey may initially be triggered by an isolated measurement of lead in hair, an elevated FEP test or other test, no decision regarding a soil lead survey should be made until blood lead data are available.

*Footnote

With few exceptions, 95% or more of the porphyrin in circulating erythrocytes is zinc protoporphyrin (ZnPP). Sometimes ZnPP is measured directly usually as μg/dl of whole blood. Sometimes in certain extraction procedures zinc is removed and the term "free" erythrocyte protoporphyrin (FEP) is used. FEP is usually reported as μg/dl of erythrocytes (FEP) or μg/dl of whole blood (EP). All three give the same information, but values differ according to whether the concentration is expressed in terms of whole blood or erythrocytes or as a ZnPP/haemoglobin ratio.

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1. Historical Lowering of Acceptable Blood Lead Concentration.

Historically, acceptable blood lead concentration has been defined as that concentration below which adverse health effects, as understood at that time, were not likely to occur. The development of the colorimetric dithizone technique for measuring of lead in biological tissues and fluids, including blood, made blood lead measurements feasible for the first time on a reasonably wide scale. The "dithizone era" lasted from the early 1930s until about 1970 when it was replaced by atomic absorption spectrophotometry (AAS) and anodic stripping voltammetry (ASV). Micro AAS methods are the most widely used ones today.

The dithizone method was cumbersome, difficult, and most laboratories required 10-20 ml of blood for a single analysis. By contrast, modern ASV techniques require only 100 microliters of blood and micro AAS methods require far less. Furthermore, it is now possible to use samples in which lead has been determined by isotope dilution-mass spectroscopy (ID-MS), the ultimate reference method for lead, and for primary standardization of alternate techniques. Furthermore, quality assurance and quality control methods have become highly developed during the past 15 to 20 years which gives greater assurance of accurate results.

Given the large amount of blood required during the dithizone era, it is not surprising that blood specimens were not usually taken unless there was strong clinical suspicion that the patient had lead poisoning. Furthermore, medical interest was concerned primarily with acute clinical disease.

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Papers published in the literature up until about 1970 dealt primarily with the diagnosis, treatment, and sequelae of acute clinical lead poisoning. Thus the upper limit of acceptable blood lead concentration in adults until about 1970 was 80 μg Pb/dl whole blood. This limit was chosen because acute lead colic was almost never encountered at lower concentrations. In children, up until 1960-1965 the upper limit of acceptable blood lead concentration was 50-60 μg Pb/dl whole blood. This was based largely on the observation that one did not encounter bands of increased density on x-ray at the growing ends of the long bones (the so called "lead line") at lower blood lead concentrations while early nonspecific clinical manifestation such as irritability and anorexia might be encountered above this level. Indeed during this era, due to the lack of availability of blood lead measurements, the diagnosis of lead poisoning in children was often based on X-ray findings and the presence of basophilic stippling of erythrocytes, both rather insensitive indices of lead absorption.

It has long been known that lead disturbs heme synthesis as manifested by increased concentration of protoporphyrin in circulating red blood cells and increased output of coproporphyrin and delta-aminolevulinic acid in urine. Reliable quantitative techniques for coproporphyrin and delta-aminoleminic acid in urine were developed in the 1950s and used rather widely in the 1960s in studies to determine the dose-response and dose-effect relationships for these metabolic evidences of toxicity due to lead. It became apparent that the blood lead threshold for these responses in both children and adults was at a PbB level of approximately 40 μg Pb/dl of whole blood (NAS/NRC, 1972). At the same time, studies in children without exposure to lead beyond that found in usual food, water and air at the time did not exhibit PbB in excess of 40 μg Pb/dl whole blood. In 1970, the Surgeon General of the United States proposed 40 μg Pb/dl whole blood as the upper limit of normal or acceptable blood lead concentration (US Dept. Health, Education and Welfare, 1971).

By the late 1960s it became apparent that chelation therapy, although effective in reducing mortality from acute lead encephalopathy, did not result in any dramatic reduction in the occurrence of permanent CNS sequelae in children with recurrent episodes of clinical lead poisoning. Interest, therefore, shifted, together with an awakening of social consciousness in the mid 1960s, from case finding and treatment to prevention of lead toxicity. The critical effect concept, as fully described in the report of the Subcommittee on the Toxicology of Metals of the Permanent Commission and International Association of Occupational Health, provided the scientific rationale and practical approach for the prevention of lead toxicity (Nordberg, 1976). Under this concept, if the "critical" or earliest measurable adverse health effect can be identified and effective action is undertaken on this basis, then later and more serious effects can be prevented. Disturbance of heme synthesis in the bone marrow was identified in this report as a critical effect of lead. At the time, the most sensitive measure reported was <u>in</u>

vitro inhibition of the activity of delta-aminolevulinic acid dehydrase in circulating red blood cells. However, the significance for health of this *in vitro* measure was uncertain.

At about the same time, micro methods for the measurement of zinc protoporphyrin in circulating erythrocytes either as zinc protoporphyrin or as "free" erythrocyte protoporphyrin became available for screening purposes. The blood lead threshold for the earliest increase in erythrocyte protoporphyrin is in the range of 15-18 μg Pb/dl whole blood (Piomelli et al, 1982; Hammond et al, 1985). In 1978, the US Centers for Disease Control recommended that the upper limit of acceptable blood lead concentration be lowered from 40 to 30 μg Pb/dl whole blood. The nature of the dose response curve for the relationship between blood lead and FEP is such that many children with blood lead concentrations even greater than 30 μg Pb will be missed on the basis of an FEP screening test. In short, the test does not have high sensitivity and specificity for lead at blood lead levels below 50 μg Pb/dl whole blood.

2. Current Reference Values.

It is clear that blood lead concentrations in the general population had been declining for at least 20 to 30 years in the U.S. and the U.K. The data prior to 1970 are based upon the use of the dithizone method, so that some of the decline may be attributable to differences in methodology. However, this does not appear to be true during the atomic absorption era as there have been no significant changes in methodology over the past 15 years or so. In the United Kingdom (U.K.), it is estimated that blood lead concentrations have been decreasing by 4-5% per year during the past decade (Quinn and Delves, 1989). During 1986 the geometric mean PbB in children and women in the U.K. was approximately 8 μg Pb/dl whole blood. Decline in PbB in the United States has been greatest during the past decade. The NHANES-II data indicate that between 1978 and 1980 mean PbB in the United States decreased from 15.9 to 9.6 μg Pb/dl of whole blood (Annest et al, 1983). It is currently estimated that mean PbB may be approximately 6 μg Pb/dl whole blood in unexposed populations in the United States (ATSDR, 1988). In the United States this decline has been attributed to sharp reductions in both air and food lead.

At the present time the World Health Organization (WHO) recommendation for acceptable blood lead concentration is no more than 2% of the population with a PbB greater than 20 μg Pb/dl of whole blood. The latest recommendation (1985) of the U.S. Centers for Disease Control in the United States is that the upper limit of acceptable PbB should be 24 μg Pb/dl whole blood. These values are comparable and suggest that the geometric mean PbB should be equivalent to 10 μg Pb/dl of whole blood or less. In the U.K. and U.S. it is recommended that any child found with a PbB equal to or greater than 25 μg Pb/dl of whole blood be investigated for the purpose of reducing that individual's exposure to lead.

3. Current Research Findings.

The most recently available studies on the neurobehavioral effects of lead during fetal life and early childhood as

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summarized by Smith et al (1989) strongly suggest that the upper limit of acceptable blood lead concentration should be reconsidered and probably lowered. It now appears that the developing nervous system is at least as sensitive to lead if not more sensitive than disruption of heme synthesis in the bone marrow. It is known that both the United States Environmental Protection Agency (EPA) and the Centers for Disease Control (CDC) are seriously considering lowering the upper limit of acceptable blood lead concentration. Current research results, primarily from the prospective studies on the neurobehavioral effects of lead during early development, would suggest that these limits may be lowered to perhaps 10 μg Pb/dl of whole blood in pregnant women and to perhaps 15 μg Pb/dl of whole blood in children.

In summary, the limits of acceptable PbB have changed substantially during the past 50 years. During each decade such limits were generally set on the basis of what was perceived at the time to be a significant adverse health effect. Initially, the aim was the prevention of acute clinical disease. The limits have also changed in relation to improving technology which has permitted the measurement of lead and its various adverse health effects at lower and lower levels as the sophistication of technology advanced. Thus, during this fifty year period one has seen a lowering of the upper limit of acceptable blood lead concentration in children from 60 μg Pb to 20-24 μg Pb/dl whole blood. It would not be surprising if this limit were further lowered during the next several years to 15 μg Pb/dl of whole blood or possibly lower in pregnant women.

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D. Other Sources of Lead

For purposes of classification, environmental sources of lead may be divided into three groups according to the concentrations of lead likely to be found in each of the sources: a) low (or baseline) dose; b) intermediate dose; and c) high dose. In general, intermediate dose lead sources are associated with moderate increases in PbB in children up to 50-60 μg Pb/dl. Such children are asymptomatic. High dose sources, while often associated with similar increases in PbB, are also associated with much higher PbB levels (greater than 80-100 μg Pb/dl). In the latter group, acute clinical symptoms are likely to be found. Fatalities have also been reported in relation to some high dose sources. For a particular source the range of PbB levels found in groups of children that have been studied may span across all three classification groups. For example, the amount of lead bearing particulates borne from workplace to home on the clothing of workers may vary widely so that some children are symptomatic while others show little effect (Baker et al, 1977).

1. Low (baseline) Dose Sources.

The general population is exposed to small amounts of lead in air, food and water. Lead in air and food have decreased dramatically in the 1980s in the United States (US EPA, 1986; ATSDR, 1988). The concentration of lead in drinking water varies widely around the world and appears to depend primarily upon the presence of lead in pipes and solder in the distribution system in areas of the world where the water is soft with an acidic pH. Such waters are generally described as "plumbosolvent" and "aggressive".This phenomenon has been intensively studied in northern England and Scotland (Moore et al, 1985). When discovered, such water supplies can be treated to reduce the plumbosolvency of the water.

2. <u>Intermediate Dose Sources</u>.

Sources in this group are generally those which con tribute to the lead content of interior household dust and in some circumstances children's play areas. Included in this group are lead-bearing particulates brought into the home on the dirty work clothing of lead workers (Baker et al, 1977; Chisolm, 1978). Removal of lead paint, particularly if flame gas torches, heat guns and mechanical sanders are used, can greatly and acutely increase interior and exterior lead bearing particulates and has been associated with clinical illness in both workers and exposed children (Feldman, 1978; Farfel and Chisolm, 1987). Similar in creases occur when amateurs and residents carry out these procedures unaware of the hazards involved (Fischbein et al, 1981; Inskip and Atterbury, 1983). Even in the absence of paint removal work, interior household dust lead tends to be higher in older housing due to the weathering and chalking of old lead based paints. Cottage industry and hobbies involving the making of pottery, other ceramic ware and art glasswork can lead to rather high concentrations of particulate lead in the household dust particularly in the areas of the home in which these activities are carried out.

The fallout from primary or secondary smelter emissions can heavily contaminate the local area. In some areas the water lead levels may be particularly high and may be associated with moderate increases in blood lead concentration. When these situations are investigated, the range in PbB concentrations found may be quite wide and include some individuals with blood lead concentrations high enough to be compatible with early clinical lead poisoning.

3. Specific and Unusual High Dose Sources.

This group includes sources in which lead is more concentrated and with which cases of clinical lead poisoning, including fatalities, have been identified. Indeed, a number of the unusual sources have only come to light following the study of individuals with severe acute clinical plumbism. Within this group, the ingestion of lead based household paint is clearly the main source of serious lead poisoning in children, particularly those with pica. Such paints may contain 1-70% lead so that tiny bits contain a highly toxic dose of lead. For example, a paint flake weighing 10 mg (about the size of a matchhead) containing 10% lead (1000 micrograms) if eaten repeatedly can over the course of a few months lead to serious clinical disease. In the United States it is estimated that 52% of the current housing stock contains lead pigment paints on exposed residential surfaces (ATSDR, 1988). Paint in defective condition constitutes an immediate and serious hazard.

Acidic beverages such as fruit juices, cola drinks, coffee and wine can leach substantial quantities of lead from improperly lead glazed ceramic ware. Children have swallowed items made of lead such as curtain weights, fishing weights, shot, jewelry

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coated with lead to simulate pearl, and jewelry with a lead base. If these items remain in the stomach the lead will be slowly dissolved. The severity of the case will depend on how long the item re mains in the stomach. The use of lead contaminated health foods (usually calcium supplements) has also led to serious disease as has the use of herbal medicines from China, other parts of Asia and Mexico. Water stored in lead-lined cisterns on rooftops, and rain barrels used as a source of drinking water in close proximity to lead emitting plants such as primary or secondary smelters can produce severe disease as has the burning of battery casings in the home for heat and the preparation of food. Sniffing of leaded gasoline has produced lead encephalopathy (Chisolm and Barltrop, 1979; Chisolm, 1985).

E. Evaluation of Data From Survey by Follow up on Case Studies.

In any survey situation it is likely that more than one source of lead will be found in a given child's environment. It is rare to find a group in which soil is the only significant source of overexposure to lead. Those who conduct surveys have an ethical responsibility to see that the subjects receive appropriate medical and environmental follow-up. While this need not be done by the survey group it is still the survey group's responsibility to refer affected individuals to an appropriate facility. Analysis of the data from the survey may indicate that there is no significant over exposure to lead in soil. On the other hand, PbBs may be log normally distributed and significantly related to lead in soil which in turn would suggest

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that lead in soil is the major source of environmental lead for the group. If the distribution of PbBs is greater than the range of PbBs acceptable in a given community a decision may be made to reduce overexposure to lead in soil. When this is done, there is a further obligation to do a follow-up survey including follow-up PbB measurements to evaluate the effectiveness of the steps undertaken under that decision.

The children who have participated in the study should also be evaluated as individuals. As a general rule, human research may only be carried out after approval of the appropriate human research committees. Ethical considerations require that research involving children may be conducted only if it is potentially beneficial to children. For this reason, data for each child must be evaluated on an individual basis not only for exposure to lead in soil but also to one or more additional sources of lead. Review of the questionnaire should help to identify other sources such as lead bearing particulates borne into the home on the clothing of lead workers, cottage industry or home hobbies, lead contaminated water supply or defective lead based paint. Ethnic groups known to use herbal medicines and/or lead bearing cosmetics require evaluation from this point of view. Blood lead values well beyond the log normal distribution of blood leads in the group (statistical outliers) suggest either severe pica with or without mental retardation or one of the high dose other sources previously cited.

Nutritional status of the group is likely to be ascertained to some extent in the questionnaire. For example, FEP values

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significantly higher than that expected for a given PbB value strongly suggest iron deficiency usually due either to inadequate nutritional intake or chronic blood loss. In any event, all children who show either PbB or FEP levels beyond the acceptable limit should be referred for a complete medical workup and therapeutic intervention if that is deemed appropriate. The basic aims of intervention are usually to improve nutrition and reduce exposure. Steps needed to reduce exposure will need to be fitted to individual circumstances. Even if the physician to whom the child is referred elects to use chelation therapy, such therapy will only be of benefit in the long run if the sources of overexposure to lead in the child's environment are identified and effectively reduced.

F. Use of Health Criterea in Deriving a Target Soil/Dust Lead Guideline Concentration

1. Choice of model

A single number for a lead in soil guideline to protect young children was considered unrealistic for a number of reasons.Various levels of blood lead concentrations are used as health standards around the world and these levels are changing as different criteria and effects of lead are considered. The environment of the population at risk can vary widely, from urban dusts derived from automotive emissions and leaded paints to smelter emissions, old mining areas, waste disposal sites or other sources. The population at risk can itself vary, to include situations where there is a high proportion of young

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children, a retirement home for the elderly, or vacant land proposed for development. Because of these considerations, the soil/dust guideline was established as a relationship or formula, in order to allow for a variety of environmental situations and regulatory criteria. A number of recent papers have discussed modelling techniques applicable to multiple source exposure to lead (Kneip et al, 1983; USEPA, 1986, 1988; Hoffnagle, 1989; Marcus and Cohen, 1989), and are discussed below. Alternate models can of course be used within the framework of this document according to the data available and any other priorities.

In the model used here, blood lead concentration is equated to a baseline level plus an increment resulting from exposure to soil or dust lead. The model takes account of the chosen blood lead guideline or target concentration and the degree of protection required in the population. The slope of the blood lead - soil lead relationship used in calculating increase in blood lead over a baseline value, and hence the soil guideline, can vary depending on a variety of factors, and this response can be adjusted for a given situation and modified as more data become available.

The relationship derived is as follows:

$$S = \frac{\left[\frac{T}{G^n} - B\right]}{\delta} \cdot 1000$$

Figure 2. Derivation of blood lead/soil lead model.

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where:

S is the <u>soil or dust guideline</u>, a geometric mean concentration in μg Pb per gram of dust (ppm)

T is the <u>blood lead guideline</u> or target concentration, in μg Pb/ dl whole blood

G is the <u>geometric standard deviation of the blood lead distribution</u>, typically in the range of 1.3 to 1.5

n is the <u>number of standard deviations corresponding to the degree of protection required for the population at risk</u>, and would normally follow from the way in which the blood lead guideline T was defined. For example if 95% of the population should have blood lead concentrations less than 20 μg/dl. n can be obtained from standard statistical tables, and some representative values are given below for different percentages of the population desired to be below the target blood lead concentration.

Percentage of population < T	approximate value of n
50	0 (target is mean)
95	1.64
98	2.05
99	2.32
99.9	3.04

B is the <u>background or baseline blood lead concentration in the population from sources other than soil and dust</u>. Data from an appropriate control group would be ideal - a group matched not only for population characteristics, but also for similar lead

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exposure from all sources except soil and dust. If there are appreciable contributions from other sources such as smelter emissions or leaded paint, these must be measured or estimated for addition to the baseline value. If these data are not readily available, any proposed investigation should evaluate the contributions from other suspected sources.

δ is the <u>slope or response of the blood lead - soil(dust) lead relationship</u> and has the units of μg Pb/dl blood increase per 1000 ppm increment of soil or dust lead.

2. <u>Factors Affecting δ</u>

The major uncertainty is the value to use for δ, the response of blood lead to increasing soil or dust lead concentration. A number of studies giving information on this relationship were considered, but it is not our intention to review them here, as most have already been considered in detail by the USEPA (1986) and by Duggan and Inskip (1985). These reviews also present a considerable number of other references relating the importance of dust and soil exposure to young children. A list of the papers considered is given in Table 1 along with details of the populations studied, the range of soil, dust and blood lead concentrations observed, and the estimated slope of the soil/dust - blood lead relationship. However, a number of observations need to be made, which bear on the choice of a value of δ to be used in this guideline model.

The range of slopes reported is wide, from 0.9 to 9.0 μg Pb/dl per 1000 ppm lead in soil or dust. Because of differences in design, the studies are not readily comparable. Some of the

Table 1

Studies Relating Blood Lead and Soil or Dust Lead Concentrations

Study	Area[1]	Soil/Dust Conc.[2] µg Pb/g (ppm)	Blood Lead[2] µg Pb/dl	Age years	Number	Est. Slope µg Pb/dl blood per 1000 ppm soil or dust	Review
Bornschein et al (1989) Telluride, CO	M	178S 281 - 567D	6	<6	94	2.2	
Moffat (1989) Dumfreis, Scotland	M	213 - 6902S 320 - 1570D	10 - 18	<12	37	1.2	
Phillips et al (1988) Herculaneum, MO	M	70 - 2258S 170 - 2080D	7 - 22	1-5	229	2.2	
Rabinowitz and Bellinger (1988) Boston, MA	U	702S (7-13,240)	6	0.5-2	195	0.9	
Laxen et al (1987) Edinburgh, Scotland	U	500D (48-13,600)	11 (3-34)	8-9	495	1.9	
Milar and Mushak (1982) Raleigh, N.C.	B	250 - 3000D	18 - 44	1-4	47	9.0	D
Reeves et al (1982) Aukland, N.Z.	U	24 - 842S	12 - 19	1-3	195	5.0	D

Table 1 (continued)

Studies Relating Blood Lead and Soil or Dust Lead Concentrations

Study	Area[1]	Soil/Dust Conc.[2] µg Pb/g (ppm)	Blood Lead[2] µg Pb/dl	Age years	Number	Est. Slope µg Pb/dl blood per 1000 ppm soil or dust	Review[3]
Stark et al (1982) New Haven, CT	U	230 - 1330S 160 - 630D	27	0-1 2-3 4-7	153 334 439	2.2 2.0 0.6	E
Roels et al (1980) Belgium	S	112 - 2560D	9 - 25	10-14	148	2.1,3.5	D,E
Angle and McIntire(1979,1982) Omaha,NE	U	81 - 339S 211 - 479D	23 - 30	1-18	831	4.0,6.8	D,E
Neri et al (1978) Schmitt et al (1979) Trail, BC	S,U	225 - 1800S	19 - 29	1-3 6	87 103	7.6,8.5 4.6,7.2	D,E
Watson et al (1978) Vermont	B	718 - 2239D	21 - 32	1-6	59	6.8	D
Baker et al (1977) Memphis,TN	S	500 - 5500D	22 - 65	1-6	32	8.6	D

Table 1 (continued)

Studies Relating Blood Lead and Soil or Dust Lead Concentrations

Study	Area[1]	Soil/Dust Conc.[2] µg Pb/g (ppm)	Blood Lead[2] µg Pb/dl	Age years	Number	Est. Slope µg Pb/dl blood per 1000 ppm soil or dust	Review[3]
Yankel et al (1977) Walter et al (1980) Silver Valley, ID	S	400 - 7500S	21 - 66	1-9	860	1.1	D,E
Barltrop et al (1975) Derbyshire, England	M	420 - 13970S 530 - 2580D	21 - 29	2-5	82	2.3	D,E
Galke et al (1975) Charleston, SC	U	173 - 1400S	32 - 41	<5	187	2.5	D,E
Shellshear et al (1975) Christchurch, NZ	U	150 - 1950S	18 - 25	1-5	60	3.9	D,E
Roberts et al (1974) Toronto, Canada	S,U	99 - 1715S 713 - 1550D	17 - 27	0-14	1125	6.0	D

Notes:

1. Area: B - battery plant, M - mining area, S - smelter, U - urban.
2. Soil (S), Dust (D) and Blood lead concentrations: means given for low and high lead areas; otherwise, range of individual results in ().
3. Review: study reviewed by D - Duggan and Inskip (1985) or E - USEPA (1986)

children studied were obviously exposed from multiple sources, and few of the studies measured all of the major sources of exposure either for individuals or adequately for the groups investigated. The age range of children was large, from less than 1 to 18 years of age, and widely differing environments were studied - smelter and battery plant exposure, old mining districts, and urban areas. Many of the baseline or background blood lead concentrations were considerably elevated by today's standards. In spite of these caveats, choices must be made, and the major factors to be considered in choosing a slope would be:

a. The age distribution of children in the population at risk -two year old children exhibiting frequent hand - to - mouth activity would be expected to have a higher δ than teenagers;

b. The physical availability of dust and soil to child - grass covered, dusty site, cleanliness of home, etc;

c. The bioavailability of lead in dust and soil. This can vary with lead concentration in the dust or soil, the adsorption capacity of the soil/dust for lead, the chemical species of lead present (mine spoil compared to urban or smelter polluted soils and dusts), age of deposit, other soil components, etc. (discussed more fully in the supplemental materials); and

d. The cultural/ethnic differences, such as parental supervision, time spent in/outside home, degree of clothing covering body surfaces, pica and mouthing habits, etc.

3. <u>Choice and Use of δ</u>

In the review papers cited above, Duggan and Inskip (1985) chose to use a value of 5 for δ, being the average of the studies reviewed. The EPA review placed particular emphasis on the results of one study (Stark et al, 1982) in that it provided good data for slope estimation, as well as providing data for both soil and house dusts for young children. These data indicate a δ of about 2 μg/dl per 1000 ppm dust or soil.

Recent studies by Bornschein et al (1989) and by Laxen et al (1987) also indicate a δ of about 2, while Rabinowitz and Bellinger (1988) report a value of 0.9 for well maintained middle class neighborhoods. Marcus and Cohen (1989) suggest a value of 2 as the most likely value, this being the median of the values reported in the papers noted in these reviews.

It would appear that a value in the range of 2 - 5 would be appropriate for most situations. However, this should be adjusted in light of particular knowledge for a given situation. Low deltas would tend to result in groups with: 1) older children; 2) well maintained of vegetative cover; 3) mine tailings (poor bioavailability); 4) cleaner homes and more frequent handwashing; or 5) heavier textured soils. Conversely, higher δ's would tend to be found in groups with: 1) children of peak lead absorbing and soil ingesting age, 18-24 months; 2) dusty conditions, sparse vegetative cover(i.e., bare soil) ; 3) homes with poor cleanliness and infrequent handwashing; 4) soil lead sources with slight soluble lead salts such as automotive and stack emissions or well oxidized and more soluble sources including exterior paint; or 5) light textured or low organic matter soils. The major influence on a value for δ may in fact be child activity, rather than any characteristics of dust or soil.

Tables 2-5 give examples of the soil guideline derived for different target blood lead concentrations and by varying other parameters in the model. Any value chosen should of course be modified in light of future research, and in particular from any investigation initiated as a result of using the guideline defined here. It must be emphasised again that these are theoretical calculations, and if adequate blood lead data are or become available, they should of course take precedence in any decision making process.

A means of setting a guideline for undeveloped land is suggested, and a number of examples of calculating a soil guideline for different situations and health criteria are also given setting a guideline based on protecting the most sensitive individual rather than a population based guideline.

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Table 2

Variation of Soil Lead Guideline
with Target Blood Lead Concentration
and Degree of Desired Protection

Target PbB	Soil Lead Standard for % of Population < Target PbB				
µg/dl	50%	95%	98%	99%	99.9%
10	3000	880	500	300	-
15	5500	2300	1860	1400	700
20	8000	3750	3000	2600	1600
25	10000	5200	4250	3700	2500

Assumptions: $\delta = 2$, Background PbB = 4 µg/dl, GSD = 1.4

Table 3

Effect of Variation in δ and Target PbB on Soil Lead Guideline

Target PbB	δ, (μg Pb/dl blood)(mg Pb/ kg soil)$^{-1}$			
μg/dl	1	2	4	8
10	600	300	150	75
15	2900	1400	700	350
20	5200	2600	1300	650
25	7500	3700	1850	925

Assumptions : 99% of population < PbB-T; GSD = 1.4, Background PbB = 4 μg/dl

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Table 4

Effect of Variation in the Geometric Standard Deviation (GSD) of the PbB distribution on Soil Lead Guideline

Target PbB	Geometric Standard Deviation					
μg/dl	1.3	1.4	1.5	1.6	1.7	1.8
10	720	300	-	-	-	-
15	2100	1400	930	520	190	-
20	3400	2600	1900	1350	920	560
25	4800	3700	2900	2200	1650	1200

Assumptions: $\delta = 2$, Background PbB = 4.0, 99% of population < Pb-T

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Table 5

Effect of Variation in Background PbB

on the Soil Lead Guideline

Target PbB	Background PbB, µg/dl				
µg/dl	2	4	6	8	10
10	1300	300	-	-	-
15	2400	1400	450	-	-
20	3600	2600	1600	600	-
25	4700	3700	2700	1700	700

In this case, 'background' could include other particular sources of lead exposure.

Assumptions: δ=2, GSD=1.4, 99% of population <PbB-T

4. Modelling the Blood Lead/Soil Lead Relationship.

A number of recent papers have discussed modelling techniques applicable to multiple source exposure to lead, (Kneip et al, 1983; USEPA, 1986, 1988; Hoffnagle, 1989; Marcus and Cohen, 1989), and should be consulted for additional discussion.

The 'disaggregate' modelling approach uses empirical relationships between blood lead concentrations and the concentrations of lead in the various media contributing to lead exposure. The slopes or responses of blood lead to differing sources are ideally estimated from regression analyses of epidemiological data. The form of this model is:

$PbB = sC_s + aC_a + dC_d + wC_w + \ldots$, where

PbB is the average blood lead concentration;

s is the slope relating blood lead and soil lead;

a, d, w, . . are slopes for air, diet, water . . ; and

C_s, C_a, C_d, C_w, . . are lead concentrations in soil air, diet, water, etc.

Proper use of this model would require measurement of all source terms as well as having good estimates for all the slopes.

The 'aggregate' model combines in a single slope or coefficient all the direct and indirect contributions of soil lead to blood lead, and also combines the contributions from all other sources into a single factor. It takes the form:

$PbB = sC_s + B$, where:

s is the slope between blood lead and soil lead;

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C_s is the soil lead concentration; and

B is the contribution to blood lead for all sources other than soil and dust.

This approach has the advantage that it is easy to understand and use, and that the necessary data are available. If any other source(s) make a significant contribution to blood lead, such as smelter emissions for example, this additional term must be measured or estimated and added to the background term B above, in order to make a proper assessment of the contribution of soil lead to blood lead.

A more complex modelling approach is used in the 'biokinetic model'. Daily lead intake from indoor and outdoor air, food, water, dust and soil are calculated using age-specific estimates of parameters such as respiratory volume, amount of soil ingestion, and lead absoption for various routes of exposure through the lungs and gastrointestinal tract. These estimates are then used to calculate an average blood lead concentration. Although this model relies on limited data for some input terms, it can be useful in predicting mean blood lead concentrations from multiple exposure sources and under alternate abatement strategies.

A modified version of the aggregate model was chosen because of its ease of use. As more data becomes available, other models could, of course, be used within the framework established in this document.

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5. The Biokinetic Model and Factors Affecting δ.

The model used in this document is based upon a change in blood lead being equal to δ times the soil lead concentration: change in PbB = $\delta \cdot C_s$. This δ can be related to the various factors used in the biokinetic model (USEPA, 1986,1988) and to the factors influencing uptake by the relationship:

δ = $(F \cdot I \cdot A \cdot X)$, where

F = age-specific factor relating amount of absorbed lead (from any source) to blood lead concentration, taken as 0.4 for 2 year old children;

I = soil or dust ingestion, mg/day;

A = per cent absorbtion of dietary lead in the gut;

X = product of factors effecting soil lead-blood lead relationship.

The multiple components of factor X can be represented as:

$X = x_1 \cdot x_2 \cdot x_3 \cdot x_4 \cdot x_5$, where

x_1 = bioavailability of soil or dust relative to normal dietary lead absorption (discussed in the bioavailability section of the report).

x_2 = factor representing physical availability of soil/dust lead. Higher for dry, dusty sites, lower for grass covered sites;

x_3 = factor indicating relative nutritional status of group. Nutritional deficiencies can enhance lead absorbtion;

x_4 = a social/ethnic index. Well scrubed, fully clothed children who spent all day indoors would be expected to have a lower soil uptake;

x_5 = any other factors which may influence lead uptake from dust and soil.

6. Guidelines for Undeveloped Land.

In setting a guideline for publicly accessible land which is to be left undeveloped, or in which the lead in soil or dust is unavailable to any young children, say by completely grassing over the site, a modified approach should be adopted. The soil guideline derived by the model adopted here would be too restrictive on land usage and unnecessary to protect public health. Two possible approaches are suggested for such a situation.

a. As soil and dust lead concentrations also follow log normal distributions, a level 2 standard deviations(say) above the guideline derived as above, could be used as a geometric mean guideline level for undeveloped sites. The appropriate formula would be:

$$U = S * G^n$$

where

U is the undeveloped land guideline, a geometric mean concentration.

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S is the guideline derived from the target blood lead concentration for deleloped land where children may be exposed to soil.

G is the geometric standard deviation of the soil/dust lead concentrations,(typically about 2).

n is the number of standard deviations chosen for the desired level of protection.

b. Alternatively, a different 'level of protection' could be chosen in the original model formula. If, for example, n=3 were to be used for populated sites, such that 99.9% of the population should be below the target blood lead concentration, a lower value could be chosen for unpopulated areas, say n=0, equivalent to where the mean blood lead concentration would be below the target blood lead concentration.

7. Examples of Soil/Dust Guideline Calculations

a) T = 15 μg/dl

n = 2.05 for 98% of population less than T

G = 1.40

B = 4 μg/dl, no other significant sources

δ = 2 μg/dl per 1000 ppm

$$S = \frac{\left(\frac{15}{1.4^{2.05}} - 4 \right)}{2} * 1000 = 1763 \approx 1800 \text{ ppm}$$

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b) as above, except take δ = 5 μg/dl per 1000 ppm

$$S = \frac{\left(\frac{15}{1.4^{2.05}} - 4 \right)}{5} * 1000 = 705 \approx 700 \text{ ppm}$$

c) as in a), except air lead contributes an additional 3μg/dl above background to the baseline blood lead concentration

$$S = \frac{\left(\frac{15}{1.4^{2.05}} - (4 + 3) \right)}{2} * 1000 = 263 \approx 250 \text{ ppm}$$

This level of 250 ppm could be used, if no measures were taken to reduce air lead exposure. If such measures were taken, an appropriate S between 250 and 1800 ppm would be recalculated.

d) as in a), except n = 3.04 for 99.9% of population less than T

$$S = \frac{\left(\frac{15}{1.4^{3.04}} - 4 \right)}{2} * 1000 = 697 \approx 700 \text{ ppm}$$

e) it is desired to set a guideline for undeveloped land using the values as in a), but with n = 0 for the mean blood lead to be below T

$$U = \frac{\left(\frac{15}{1.4^{0}} - 4 \right)}{2} * 1000 = 5{,}500 \text{ ppm}$$

f) given the guideline of 1800 ppm found in a), it is desired to set a guideline for undeveloped land at 2 standard deviations above the soil mean, using a soil lead geometric standard deviation of 2.0

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$U = 1800 * 2.0^2 = 7200$ ppm

g) as in f) above, but taking the mean of 700 ppm found in b) as a starting point

$U = 700 * 2.0^2 = 2800$ ppm

h) $T = 25\ \mu g/dl$

$n = 3.04$, for 99.9% of population less than T

$G = 1.43$

$B = 5\ \mu g/dl$

$\delta = 2\ \mu g/dl$ per 1000 ppm

$$S = \frac{\left(\dfrac{25}{1.43^{3.04}} - 5\right) * 1000}{2} = 1714 \approx 1700 \text{ ppm}$$

i) as in h), except n = 3.71 for 99.99% of population less than T (10 out of every 100,000 at risk)

$$S = \frac{\left(\dfrac{25}{1.43^{3.71}} - 5\right) * 1000}{2} = 816 \approx 800 \text{ ppm}$$

j) given the guideline of 800 ppm found in b), it is desired to set a guideline for amenity grassland at 2 standard deviations above the soil mean, using a geometric standard deviation of 2.10.

$U = 800 * 2.10^2 = 3528 \approx 3500$ ppm

k) it is desired to set a guideline for the amenity grassland using the values as in h), but with n = 0 for the mean blood lead to be below T

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$$U = \frac{\left(\frac{25}{1.43^{0}} - 5 \right)}{2} * 1000 = 10{,}000 \text{ ppm}$$

8. Lead in Soil/Dust Guideline Based on the Most Sensitive Individual

The guideline setting approach previously discussed is based upon deltas derived from population studies - in effect a mean response of blood lead to soil or dust lead. Rather than basing a guideline upon a certain percentage of the population being below a target blood lead concentration, say 98% less than 15 μg/dl for example, it may be desired to base a guideline on protecting the most sensitive individual. Such an individual would be the child who ingests large amounts of soil.

In its current use of the biokinetic model, the USEPA (1988) makes use of the studies of Binder et al (1986) and Clausing et al(1987) on estimating the amount of soil ingested by the average child. Current estimates are that this is about 100 mg/day for a two year old, with the 95th percentile about 0.5 g/day and the 99th percentile about 5 g/day. From the relationships previously discussed, delta may be taken to be proportional to the average daily amount of soil ingestion. Using the 'best mean estimates' of 2 for δ and 100 mg/day for soil/dust ingestion, a soil guideline can be calculated for various amounts of soil ingestion which would result in a maximum allowable increase in blood lead concentration above a basline value. Table 6 illustrates how this may be done for a particular set of assumptions.

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Table 6

Soil/Dust Guideline Calculated For Varying Amounts of Soil Ingestion

And Baseline Blood Lead Concentrations Target PbB of 15 μg/dl Assumed

	Soil/Dust Guideline, μg Pb/ g			
Soil Ingestion	Baseline Blood Lead, μg/dl			
mg/day	0246			
100	7500	6500	5500	4500
500	1500	1300	1100	900
1000	750	650	550	450
2500	300	260	220	180
5000	150	130	110	90
10000	75	65	55	45

Using these assumptions, a lead in soil guideline set on the basis of high soil ingestion by a child results in a standard within the range of "normal", uncontaminated soil lead concentrations.

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VI. BIOAVAILABILITY

The bioavailable fraction of the total quantity of Pb in a diet is generally defined as that fraction which can be absorbed into the blood stream by the animal species ingesting the diet. Because food constituents also affect Pb absorption, the bioavailability of Pb in test materials such as soil is compared to that of the soluble Pb salt, Pb-acetate, which is considered 100% bioavailable. Research has shown that many factors can influence whether lead in soil and dust ingested by children is actually absorbed into the blood. Physical and chemical properties of the dust particles, nutritional status of the children, and whether the soil is ingested with food or between meals, can each substantially affect whether soil Pb is absorbed. These factors can so strongly affect Pb absorption that decisions to replace polluted soils should consider whether the nature of the Pb species present, and the nature of the soil involved.

Another very important consideration is the effect of increasing soil dose on Pb absorption. If the <u>pica</u> child is to be protected, soil ingestion of the 95th or 99th percentile child (0.5 and 5.0 g/day, respectively; Calabrese et al., 1989) must be considered. However, if Pb absorption approaches a plateau with increasing soil dose, the pica child may be at no greater risk than the median soil-ingesting child. The response to increasing soil dose has been found to plateau in several studies, supporting this model. Further, the adsorption of Pb to soil particles in the small intestine would be expected to cause this response pattern. Similarly, adsorption of Pb by soil particles in the intestine allows low soil Pb concentrations to be essentially unavailable compared to higher soil Pb concentrations. Approximately 300 mg Pb/kg was found to be a "no effect" level for Pb in sewage sludge compost ingested by cattle; below this level tissues were not increased in Pb even though the cattle ingested significantly increased amounts of total Pb. Thus, risk from soil Pb is very different than risk from water-Pb, paint-Pb, or food-Pb because these Pb sources do not provide Pb-adsorption capactity along with the ingested Pb.

A. Factors That Influence Risk of Soil Lead (Pb)

Pb concentration in soil, size of soil particles rich in Pb, chemical species of Pb in soil, and nutritional factors together interact with human behavioral factors in controlling risk from soil Pb. It is clear from many studies that children vary remarkably in blood Pb (Pb-B) when exposed to similar Pb sources. Parental supervision, personal habits (mouthing of fingers, hands, toys; chewing fingernails; washing hands), *pica* behavior, and quality of nutrition vary among children so greatly that some children may have little risk when they live or play in areas with high soil Pb. However, it is necessary to consider the child described by Duggan and Inskip (1985), the average child playing in a normal dirty way. Other authorities (e.g. US-EPA) consider the "most-exposed, most-susceptible individual" (the MEI). In the case of soil Pb risk analysis, this MEI is a poorly-supervised child who is regularly exposed to Pb-rich soil, has *pica* for soil, and has poor nutrition for factors which interact with Pb absorption. Such a child would therefore ingest much soil Pb, and absorb a higher percentage of this soil Pb than would the well-cared-for child.

B. Bioavailability of Ingested Soluble Pb

Research on laboratory animals over many years has characterized the effect of nutritional factors on Pb absorption (Mahaffey, 1982, 1985; Mahaffey and Michaelson, 1980). More recently, adult human Pb isotope absorption studies and Pb balance studies in infants have clarified the understanding of human Pb absorption. In addition, several feeding studies using livestock and laboratory animals have directly tested Pb absorption from dietary soil/dust.

C. Effect of Pb Compound and Particle Size on Pb Absorption

Research has been conducted to evaluate the bioavailability of Pb in different Pb-compounds. Allcroft (1950) reported on long-term feeding studies in which several Pb compounds were fed to cattle, and found great differences between both Pb compounds and different particle sizes of the same compounds. In particular, large particle PbS had much lower toxicity and caused lower tissue levels of Pb than did small particle PbS or other compounds.

Barltrop and Meek (1975, 1979) studied bioavailability of different Pb compounds and paint pigments (of varied particle size) to rats using a 48 hour feeding period. In their work, larger particles had lower bioavailability than smaller particles of several materials. This would appear to result from the poorer dissolution of larger particles during the short period of acidic treatment in the stomach. Compounds which are readily dissolved in weak acid were highly bioavailable. Thus, some Pb pigments, Pb ores, and paint particles are only partially dissolved in the stomach. Human feeding studies of Rabinowitz et al. (1980) tested the absorption of finely divided PbS to fasting human volunteers. In this test, PbS was highly bioavailable, but this PbS preparation does not simulate Pb ore or Pb ore wastes. More recently, Healy et al. (1982) tested the solubility of different particle size preparations of PbS in gastric fluid. This work confirmed that smaller particles of PbS were dissolved more rapidly than larger particles. Their work was focused on bioavailability of PbS from cosmetics (e.g. surma) which appear to be transferred to the mouth after hand contact (Healy et al., 1982; Healy, 1984). The implication of these findings for soil Pb are that larger particle size PbS (e.g. galena ore particles dispersed by mining, transport, or smelting) would be expected to have significantly lower bioavailability than other soil Pb.

D. Effect of Nutritional Factors on Pb Absorption

Feeding studies to assess the effect of nutritional status, on Pb absorption have shown that a deficiency of calcium (Ca) or iron (Fe) increase Pb absorption (Mahaffey, 1981, 1985). When dietary Ca fell below about 50% of the dietary levels recommended by the National Research Council (NRC) for growing rats, Pb absorption strongly increased (Mahaffey et al., 1977). Mahaffey (1981) has summarized these nutritional interactions in relation to known dietary limitations in urban poor children and pregnant women, the largest groups who comprise the "most-susceptible" individuals for excessive soil Pb.

Iron deficiency was also found to strongly affect Pb absorption in rats. Pb absorption declined with a further increase in dietary Fe above the minimum dietary requirement. Because many children are Fe deficient, this nutrient could be important in assessing risk of soil Pb ingestion. However, results from two independent research programs found opposite effects of Fe-deficiency on Pb absorption by adult humans. The Watson et al. (1980) study reported that individuals with low serum ferritin (indicating low body Fe reserves), who absorb an increased fraction of dietary Fe, also absorbed increased amounts of carrier free Pb. However, Flanagan et al. (1982), using ^{203}Pb with 200 μg carrier Pb, found no effect of Fe status (serum ferritin) or added dietary Fe on Pb absorption by humans. This was a direct test of the Watson et al. report, but used an improved experimental design.

One of the most important findings of this human Pb absorption research was that Pb absorption is greatly reduced by simultaneous ingestion of food (Blake et al., 1983; Flanagan et al., 1982; Heard et al., 1983; James et al., 1985; Chamberlain, 1987; Rabinowitz et al., 1980) compared to Pb ingested during fasting. The effect of a meal on Pb absorption lasted about 2-3 hours after eating because of slow gastric emptying after a meal (James et al., 1985). This result has important implications for absorption of soil/dust Pb compared to water Pb or paint Pb ingested between meals. Studies of which dietary components reduce Pb absorption identified minerals (Ca, phosphate (P), phytate (inositol hexaphosphate), and fibre (Blake et al., 1983;

Blake and Mann, 1983; James et al., 1985). Combinations of Ca and P had more effect on Pb absorption than did Ca alone (Blake and Mann, 1983; Heard et al., 1983). In other work, Pb isotopes were incorporated into lamb liver and kidney, and into spinach to allow comparison of Pb intrinsic to a food with Pb isotope extrinsically added to a meal with that food. This research showed that "food" Pb was absorbed equal to Pb salts added to an equivalent meal (Heard et al., 1983).

Pb in oysters was about 70% as bioavailable to Japanese quail as Pb acetate added to the purified diet (Stone et al., 1981). James et al. (1985) evaluated a number of meals and dietary components. Test meals components such as phytate or EDTA (ethylenediaminetetraacetate) reduced Pb absorption compared to the effect of an equal amount of Ca and P in a low phytate refined diet basal meal (James et al., 1985; Flanagan et al., 1982). On the other hand, milk in a meal increased Pb absorption compared to the expected effect of an equivalent amount of Ca and P in the milk. Thus, phytate, fibre, and Ca in whole grain foods would tend to appreciably reduce Pb absorption compared to more highly refined grain products.

As observed with other nutrients, Pb absorption is proportional to the activity of free Pb^{2+} ions in the intestine. For example, addition of EDTA to a test diet reduced absorption (Flanagan et al., 1982; James et al., 1985) because chelation of an element reduces its chemical activity. The role of phytate (James et al., 1985; Wise, 1981), and some tannin and fibre components (Peaslee and Einhellig, 1977; Paskins-Hurlburt et al.,

1977) should be similar to EDTA. Soil and dust should act like fibre in this regard, by adsorbing Pb and reducing Pb^{2+} ion chemical activity, thereby reducing soil Pb bioavailability.

These results on the importance of Ca and P concentration in test human diets on Pb absorption raises the question "How do Ca and P interfere with Pb absorption?" There are several possible mechanisms. One is simple interaction of Ca and Pb at the intestinal Pb absorption site. However, this mechanism would not explain why P is shown to be significant in humans. The most likely mechanism for the effect of Ca and P on Pb absorption appears to be co-precipitation of Pb with Ca-phosphates formed during the digestion process. Co-precipitation of Zn with Ca-phosphates indicates how this might occur. Nelson et al. (1985) first studied model systems and found that Ca-phosphate quickly (within minutes) formed when Ca and PO_4 were present at levels common in whey, the solution remaining after curds form in acidified cow's milk. Further study showed that Zn coprecipitated with the Ca-phosphates above pH 5.0 as the pH increased and coprecipitation was complete by pH 6.0 (Nelson et al., 1987).

This may be very likely the model for the effect of dietary Ca and P on Pb absorption. The clear interaction of dietary Ca and P concentrations in animal and human studies of Pb absorption fit a solubility product model. Pb coprecipitation with Ca-phosphate should be complete at even a lower pH than found for Zn.

E. Bioavailability of Lead in Ingested Soil and Dust

One approach to this question is what happens to wildlife who live in areas with high soil Pb. Wildlife are unable to avoid exposure to and usually show at least some absorption of soil/dust Pb from their habitat (Elfving et al., 1978; Hutton and Goodman, 1980; Ireland, 1977; Scanlon et al., 1983; Young et al., 1986). These studies suggested appreciable bioavailability of soil/dust Pb, but did not make specific comparison with soluble Pb salts added to control diets. Similarly, livestock grazing pastures on soils rich in Pb (mine wastes, naturally Pb-rich soils) had increased Pb levels in body tissues showing soil Pb had at least some bioavailability, but much less than for soluble Pb sources (Allcroft, 1950; Egan and O'Cuill, 1970; Harbourne et al., 1968; Wardrope and Graham, 1982).

The "contribution from lead in mining wastes to blood lead" has recently been addressed in a comprehensive review by Steele, et al (1990). Their evaluation of studies for mining areas found no strong correlation between soil lead and blood lead and no elevated blood lead concentrations in areas with very high soil lead concentrations (Heyworth, 1981), or slopes at the low end of the range as noted by the EPA (Barltrop, et al, 1975; Barltrop, et al, 1988). The report notes that while epidemiological studies may not be conclusive, when viewed together, they do indicate that mining wastes may be different from other soil/dust lead sources in contributing to blood leads.

The extensive report by Steel et al. (1989) also indicated that the possible reasons for a reduced impact of lead sulfide in

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soils contaminated by mine wastes (PbS is the Pb chemical species from Pb ore remaining in mine tailings) on blood lead in children living in mining communities are that mine wastes have larger particle size which decreases the bioavailability of lead in the gastrointestinal tract. Also lead sulfide resists absorption in the gastrointestinal tract when compared to other forms of lead.

Several studies were conducted to directly test the bioavailability of soil/dust Pb to animals. Stara et al. (1973) reported studies of rats fed tunnel, highway, or smelter dusts. Accumulation of Pb in bone or kidney was non-linear with dose (Table 7), with lower %-absorption as dose increased. Bone lead tended to approach a plateau as the amount of soil Pb in the diet increased. Another way to view these results is that the highest %-absorption of soil Pb occurred at the lowest soil ingestion level. Table 8 shows results from their comparison of the absorption of Pb by rats fed different dust sources. El Paso smelter dust (0.67% Pb) had appreciably lower effect on blood Pb than Queens tunnel dust (2.22% Pb) or Los Angeles freeway dust (1.04% Pb) when the rats were fed 1 mg Pb/d as dust in gelatin capsules, equivalent to about 100 mg Pb/kg diet. Bone and kidney Pb were also lower for the lower Pb concentration smelter dust than for the tunnel or freeway dusts. These tests did not compare absorption of Pb from dusts with Pb acetate. This work used a purified diet rather than a lab chow diet which favored Pb absorption.

Dacre and TerHaar (1977) conducted an evaluation of the bioavailability of Pb in houseside soil (990 mg Pb/kg) and roadside soil (2300 mg Pb/kg) compared to Pb acetate. Equal Pb concentrations were added to diet from the three sources, 50 mg Pb/kg diet. A high fibre, high nutrient rat chow was used as the basal diet. Much lower blood-Pb and bone-Pb levels were reached in their experiment than seen by Stara et al. (1973) (Table 9). Bone and kidney Pb concentrations after 90 days feeding showed that soil Pb had significantly lower effect than Pb acetate. Bone results indicated that soil Pb was about 70% as bioavailable as Pb acetate.

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Table 7

Effect of the daily dose of ingested dust-Pb on Pb in tissues of rats fed Queens, NY tunnel dust (sieved) mixed in purified diet for 42 days before analysis of tissues. Dust contained 22 g Pb/kg (Stara et al., 1973).

Daily Dose	Blood Peak Pb	Tissue Pb Femur	Kidney	Liver	Brain
mg Pb/d	μg/dL	------- μg Pb/g tissue --------			
0.0	11	0.75	-	0.13	0.032
0.5	33	25.7	2.5	0.56	0.030
1.0	39	33.6	3.2	0.52	0.055
5.5	51	66.1	9.4	1.3	0.28

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Table 8

Effect of dust source and Pb concentration on Pb in tissues of rats fed dust supplying 1 mg Pb/day for 36 days. (Stara et al., 1973).

Dust Source	Dust-Pb	Blood Peak-Pb	Tissue Pb Femur	Kidney	Liver	Brain
	mg/g	µg/dL	------- µg Pb/g tissue -------			
Control	-	12	0.75	-	0.13	0.032
NY Tunnel	22.2	45	33.6	3.2	0.52	0.055
LA Freeway	19.4	39	32.5	2.7	0.32	0.094
El Paso Smelter	6.7	32	23.6	2.5	0.36	0.035

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Table 9

Bioavailability of soil Pb compared to Pb acetate fed to rats at 50 mg Pb/kg diet for 30 or 90 days mixed in a laboratory chow diet (Dacre and TerHaar, 1977). Roadside soil fed at 2.15% of diet; houseside soil fed at 5.0% of diet.

Diet	Soil Pb Concn.	Measured Diet Pb	Bone Pb, mg/kg @ 30 days	Bone Pb, mg/kg @ 90 days	Kidney Pb @ 90 days
	mg/kg	mg/kg	mg Pb/kg		
Control	-	0.6	1.71 a	1.27 a	0.25 a
Roadside	2300	56.0	5.93 b	4.48 b	0.77 b
Houseside	990	51.8	5.20 b	4.98 b	0.76 b
Pb acetate	-	49.1	5.21 b	6.28 c	0.96 c

Means in a column followed by the same letter are not significantly different.

Chaney et al. (1984) reported data from a more detailed evaluation of the effect of soil on dietary Pb absorption (Table 10). Rats were fed purified complete casein-sucrose purified diets with and without 5% uncontaminated soil, and with and without 50 mg Pb (as Pb acetate)/kg diet to test the effect of dietary soil on absorption of soluble Pb salts (50 mg Pb/kg diet and 50 g soil/kg diet = 1000 mg Pb/kg "soil" during test). Rats were also fed five Baltimore urban garden soils to compare bioavailability of real Pb-rich urban soils with that of Pb acetate. All Pb was added at 50 mg Pb/kg dry diet (unequal soil amounts). The results are shown in Table 10. Bone Pb concentrations were used to evaluate diet Pb bioavailability. The addition of 5% uncontaminated soil to the diet reduced Pb acetate control to 53% of Pb acetate alone. Four soils with about 1000 mg Pb/kg yielded bone Pb about 24% (15-44) of Pb acetate, while a garden soil with 10240 mg Pb/kg yielded bone Pb 70% of the Pb acetate control. Pb in real soils was appreciably less bioavailable than was Pb-acetate freshly mixed with soil. The general trend showed increased soil Pb bioavailability at higher soil Pb concentration (when soil Pb concentrations were higher, percent soil in the diet was correspondingly lower). This may be expected because soil acts like a fibre and a Ca and P source in the diet. These properties should allow soil to adsorb Pb in the lumen of the intestine and reduce net Pb absorption.

The use of purified diets (Chaney et al., 1984) yielded much greater Pb absorption from dietary soil than that found by Dacre

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Table 10

Effect of soil on bioavailability of Pb to rats, and bioavailability of Pb in urban garden soils.

Treatment[1] PbOAc	Soil	Pb in Tibia mg/kg tibia ash mean ± std. err.	Pb absorption compared to that of Pb acetate, %
-	-	0.3 ± 0.3 e[2]	-
-	11[3]	0.0 ± e	-
+	-	247.0 ± 10.1 a	100
+	11[3]	130.0 ± 29.5 bc	53
-	706	40.0 ± 6.1 de	16
-	995	108.0 ± 26.3 c	44
-	1080	37.1 ± 7.3 de	15
-	1260	53.6 ± 7.4 d	22
-	10240	173.0 ± 21.8 b	70

[1]A purified casein-based complete diet was fed to Fisher rats for 30 days. Pb acetate and garden soils were added to supply 50 mg Pb/kg dry diet. The experimental garden soils comprised 7.08, 5.02, 4.64, 3.95, and 0.488 % of the dry diet, respectively; control soil was fed at 5% of diet.

[2]Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's Multiple Range Test.

[3]Unpolluted farm soil near Beltsville, MD, (Chillum silt loam, 11 mg Pb/kg), similar to original soil in the urban gardens used in this experiment.

and TerHaar (1977). The experimental protocols were similar, and dietary Pb was fed at the same level. Pb in tibia ash reached 247 mg Pb/kg in rats fed 50 mg Pb (Pb acetate)/kg purified diet, but femur Pb reached only 5-7 mg Pb/kg in rats fed the same level of Pb in a lab chow diet (Dacre and TerHaar, 1977). Mahaffey and Michaelson (1980) discussed this phenomenon, and stated it resulted from the much higher levels of Ca, Fe, and fibre in chow diets compared to "NRC" purified complete diets. A similar effect of diet was observed by Mylroie et al. (1978) in a direct comparison of diet type on the absorption of paint Pb (Table 11). Much higher bone and kidney Pb were reached using the purified complete rat diet normally recommended for toxicology studies. In many ways, these purified diets are similar to US diets because of low fibre and mineral levels (Mahaffey, 1985).

Research on risk from Pb in ingested sewage sludge also provides data relevant to the question of bioavailability of urban soil Pb. Sewage sludge has been added to usual (or practical) diets of livestock to evaluate food chain transfer (bioavailability) of Pb and other potentially toxic materials in the sludges. Substantial percentages of sludge in diets were used to simulate poor livestock management (worst case) situations in which cattle ingest up to 14% soil (Fries et al., 1982). Sludges used in these studies contained varied levels of Pb and other elements such as Fe and Ca known to interact with Pb. Studies reported by Kienholz et al. (1979) and Johnson et al. (1981) in which cattle ingested sludge with 780 (Table 12) or 466 mg Pb/kg, respectively, found increased bone, liver, and

Table 11

Effect of lab chow versus purified diet on absorption of Pb from paint chips fed at 1% of diet for 35 days. Paint contained 10% Pb as Pb-octoate; diets contained 1000 mg Pb/kg (Mylroire et al., 1978). Diet type affected tissue Pb concentration in each tissue ($P < 0.01$).

Diet Type	Pb-Blood	Pb-Femur	Pb-Liver	Pb-Kidney
	µg/dL	-------- µg/g wet weight --------		
Lab Chow	<10	97	0.24	5.6
Casein-sucrose	140	400	2.7	300.

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Table 12

Effect of percentage of sewage sludge in diet on Pb residues in tissues of cattle which consumed the test diets for 180 days (Kienholz et al., 1979). The digested sludge was from Denver, Colorado, and contained 780 mg Pb/kg.

Sludge in Diet	Diet Pb	Pb in tissues Kidney	Liver	Bone
%	mg Pb/kg dry wt.			
0	0.5	0.9 a	0.2 a	0.8 a
4	29.0	12.2 b	3.3 b	3.7 b
12	80.0	15.8 c	4.6 c	11.0 c

Within a column, means followed by the same letter are not significantly different at the 5% level.

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Table 13

Effect of percentage of sewage sludge compost in diet on Pb residues in tissues of cattle which consumed the test diet for 180 days (Decker et al., 1980). The compost contained 215 mg Pb/kg, and high levels of Fe and Ca.

Dietary	Pb concentration					
Compost	Diet	Feces	Duodenum	Liver	Kidney	Femur
%	------------------mg Pb/kg dry weight-----------------					
0.	6.0 a	14.7 a	2.81 a	2.36 b	3.96 ab	3.70 a
3.3	11.2 b	23.8 b	3.18 a	2.48 b	5.26 a	4.74 a
10.0	19.9 c	46.7 c	4.21 a	8.44 a	2.92 b	3.37 a

Within a column, means followed by the same letter are not significantly different at the 5% level.

kidney Pb. Response was curvilinear, with the slope of increase in tissue Pb decreasing at higher sludge dose.

In other studies, cattle grazing pastures amended with sludges or sludge compost containing lower amounts of Pb (380 mg/kg) had no significant change in bone or liver Pb concentration (Decker et al., 1980). Cattle fed sludge compost containing 215 mg Pb/kg had little change in bone Pb (Table 13). This confirms that the soil matrix can greatly reduce the bioavailability of Pb in ingested soil-like materials. This work also indicates that soil may adsorb Pb so strongly that Pb-B is not increased until some threshhold soil-Pb concentration is exceeced. The threshhold was found to be about 300 mg Pb/kg for sewage sludge compost ingested by cattle (Chaney et al., 1989).

Many scientists have considered the bioavailability of Pb in ingested soil and dust (Chaney et al., 1984; Day et al., 1979; Duggan and Inskip, 1985; Ferguson, 1986; Gibson and Farmer, 1984; Harrison et al., 1981; Thornton, 1986). Some have conducted chemical extractions to simulate conditions of the stomach, and found soil Pb was very soluble (Chaney et al., 1984; Day et al., 1979; Duggan and Inskip, 1985; Ferguson, 1986; Harrison et al., 1981). Although some argue that solubility means availability, the above research shows that soil components may adsorb stomach-solubilized Pb at the pH of the intestine and thereby reduce Pb absorption. This effect would cause increased Pb absorption at higher soil/dust Pb concentration at any particular Pb dose. Further, the above research showed that a decreasing response slope results when increasing amounts of a soil are fed.

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These responses are different characteristics of the bioavailability of soil Pb in the diet.

F. Potential Importance of Stomach pH on Absorption of Pb from Ingested Soil and Dust.

Questions have been raised about which soil properties most reduce Pb bioavailability and which experimental animal species might be the most appropriate models for determining the risk to infants/children from the Pb in urban soils, mine wastes, Pb-ore concentrates, smelter wastes, and Pb-paint contaminated soils. Because of the potential effect of stomach acidity on rate of dissolution for PbS, etc., stomach pH was re-considered. In particular, an evaluation was made of stomach pH and the effect of soil ingestion on soil pH of humans, pigs, and rats, because of the apparent importance of stomach pH in the dissolution of PbS and soil Pb. Many Superfund sites involve mine wastes which appear to contain predominantly PbS. If PbS has low bioavailability to humans under normal environmental exposure conditions for the worst case children, the cost of remediating these sites may be much reduced if the Pb in the mine waste/soil is known to have lower bioavailability than that found in soils contaminated by smelter emissions, automotive emissions, or paint residues. These latter sources have been found to cause increased PbB in children exposed to soils when soil Pb exceeds 500-100 mg/kg (CDC, 1985; EPA, 1989 OSWER directive; EPA, 1986 Air Quality Criteria Documents; Duggan and Inskip, 1985). Pb-B in children exposed to PbS in mine wastes or ore concentrates appeared to have substantially lower response to this source than seen in other populations exposed to more soluble Pb species in soil or dust (Middaugh et al., 1989; Steele et al., 1990).

Research has shown that PbS dissolution is very dependent upon pH. The chemical solubility of PbS responds to both pH and particle size (Healy et al., 1982, Roy, 1977). Because of the short incubation of food in the stomach, and possibly because of the pH buffering of food, mine wastes, PbS, and larger particle size materials should not be expected to be dissolved in the stomach. PbS was found to be very much less soluble in human gastric juice than were Pb carbonates and sulfates (Carlson and Woefel, 1913; Woefel and Carlson, 1914). Chamberlain et al (1978) fed fine PbS with food to human volunteers and found about 6-12% absorption.

Thus, the actual pH of the stomach contents during digestion of soil might be very important in assessing risk from soil ingestion. Researchers on microelement nutrition have considered the pH of the stomach and the duodenum in order to develop *in vitro* Fe bioavailability assays (Miller et al., 1981; Schricker et al, 1981; Reddy et al, 1988). It is difficult, but one must consider stomach pH under both the fasting condition and the effect of food (or soil) on the pH of the stomach contents. The number generally described as the pH of the stomach is the pH of gastric fluid secreted by fasting individuals. Actually, much is known about this because the importance of gastric fluid pH on ulcer development in humans. Hereditary, hormonal and dietary influences on gastric acid secretion cause pH to vary from 1.0 to 2.5 (or even as high as 7 with poor ability to secrete stomach acid, e.g. in achlorhydria; Bezwoda et al., 1978). However, as soon as food is ingested, the buffering capacity of the food causes the pH of the stomach contents to rise (Longstreth et al., 1975; Malagelada et al., 1976; Malagelada et al., 1977; Malagelada et al., 1979). Many of the techniques developed and studies conducted gained more information about the nature of ulcer disease in humans which was a result of excessive gastric acid secretion or sensitivity of stomach or duodenal tissues to stomach acid. Compounds used to counteract ulcer inhibit acid secretion, and raise the pH of the stomach (e.g. Lucey et al., 1989). Antacids also react with gastric acids to raise stomach pH. Therefore, soil would also cause the pH of the stomach to rise. The presence of $CaCO_3$, especially finely divided $CaCO_3$ in calcareous soils, but also neutral soils with higher cation exchange capacity, would cause a similar increase in pH of the stomach contents.

It is generally agreed that normal gastric fluid pH is 1-2 in rats, pigs, and children. However, infant (pre-weaning, <24 days old) rats have high stomach pH (6-7), and the transition to strongly acidic stomach pH is delayed as compared to children (Takeuchi et al., 1981). Dr. L. R. Johnson (1990) who had performed extensive research on gastrointestinal physiology with rats noted that another likely source of possible misunderstanding about stomach pH results from the way we manage rats. The fasting rat stomach fluid pH is 1-1.5; however, the rat usually eats intermittently/continuously (nibbles), and much data about the rat stomach pH shows a higher pH level because food is present in the stomach. The human eats meals, and accumulates a "basal" gastric fluid of pH 1-2 in the antrum of the stomach. But when food is ingested, the pH rises to 5-6. The rat continuously secretes stomach acid, and secretion responds to several hormone activities. The human has a low basal secretion, but hormones significantly increase acid secretion when food is ingested or the stomach is distended. When fed rat chow, the rat stomach empties slower than do human stomachs, but this may be an artifact of the highly digestible type human foods compared to rat chow. Johnson (1990) notes that rat and human stomach pH levels are not that dissimilar, and that rats are a valid model for processes which are pH dependent such as PbS dissolution. Both secrete a solution which is about 100-150 mM HCl.

Another source of information about stomach pH comes from the work of Dr. G. Bates (1990) who has been studying the bioavailability of food Fe, and trying to develop *in vitro* methods to assess the bioavailability of Fe. This *in vitro* work used cannulated miniature pigs were fed test meals, then gastric fluid and duodenal fluid were sampled. A pinto bean meal caused stomach pH to be 5.1, 4.0, and 3.1 at 30, 60 and 90 minutes after introduction of the homogenized slurry of pinto beans test meal (not by stomach tube) (Reddy et al., 1988). These pH levels are very similar to the results for adult humans from Malagelada et al. (1976; 1979).

These considerations indicate that the stomach pH of rat, pig, and human children are not different enough to justify use of the pig rather than the rat in assessing bioavailability of Pb in soils and mine wastes. Because of the potential extreme public expense in remediating Pb polluted urban soils and mine wastes, important principles of soil-Pb bioavailability shown in rats may need to be confirmed in pigs and primates to win public acceptance of these costs.

It is important to consider that food and soil can buffer the pH of the stomach to high levels, > pH 6, greatly reducing dissolution of environmental PbS and/or soil-Pb. Limestone in soil or mine wastes, or higher cation exchange capacity neutral pH soils might consume gastric acidity and thus allow the digesta to enter the small intestine without receiving the strong acid attack normally assumed to take place in the stomach.

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VII. RISK MANAGEMENT

A. Risk Assessment/Management

The overall analysis of risk due to an environmental contaminant has been systematized by the National Academy of Sciences (NAS, 1983). In this approach, the risk assessment is composed of two parts; namely, hazard assessment and exposure assessment. Associated with the risk assessment in the overall analysis is the area of risk management. The main focus of the present discussion is on exposure assessment and in particular development of a relationship between blood lead levels and the levels of lead in soil as one possible source of exposure.

The objective of this analysis is a suggested soil lead guidance based on the relationship between levels of lead in soil and the results of blood lead levels. This relationship forms part of the exposure assessment. Other parts of the exposure assessment include contributions to blood lead levels due to dust, water, food, paint and other sources. The overall exposure assessment includes all these potential sources.

The specific blood lead level at which there is a health concern is a matter of present debate in the public health community as discussed in detail in a previous section of this report. As consensus develops concerning a specific number, this allows the suggested soil lead guidance to be scaled accordingly.

The overall risk assessment can be achieved on a site specific or case-by-case basis. If the major exposure route is from the soil then the suggested guidance developed here can be applied directly to determine clean up levels.

Risk management has several inputs. One is the risk assessment as previously described. In this case the limited question of the relationship between blood lead levels and soil lead concentration is considered. However, it must be recognized that in deciding on clean up strategies, several other factors impinge on the decision process. Other aspects of the risk assessment can change the decision such as the use of different blood lead levels of concern from the hazard assessment and exposures to lead from sources other than soil. Several other factors are involved in the risk management decision process; viz, economic, legal, political and social. It is not the purpose of the current analysis to address these other aspects, only to note their existance.

The area of risk assessment has been addressed by the Federal Government (1983) Hallenbeck, et al. (1986), Ricci (1985) and Rowe (1977) which may also serve as suggested reference material.

B. Risk Communication

There are three methodologies concerned with estimating risk: risk assessment, risk management and risk communication. Prior to 1986 there was little literature on the subject of risk communication. Since that time many articles have appeared and conferences and special sessions have been conducted on this topic. The importance of this methodology is in the increasing awareness of disonances and tensions between the risk assessment experts and the lay communities. Risk communication represents a new policy focus that addresses the problem of the divergence

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between expert approaches and lay perceptions of risk. The broad question that underlies this subject is; how can experts and the general public communicate about uncertain environmental hazards in a manner that both educates the public, informs the experts and respects the democratic process. Risk communication has been discussed by Davies (1987) and Covello, et al (1988) along with Guidebooks (1986); Community dialogue (1988) and perceptions of risk (1980).

A number of factors can contribute to the trust and confidence that can be established by a successful risk communication program. These factors include; consistency in the risk estimate message and in the people communicating this message, independent corroboration of the risk assessments by external scientific adivsory boards, easy public access to official regulatory agency information and data, understanding inconsistencies between scientific and popular views, not to assume that good risk communication correlates directly with a change in behavior and collaboration between federal, state and local agencies.

A number of often incorrect and unspoken assumptions underlie the view some take to risk communication. Too often it is assumed that the risk assessment is done well and without bias and that such an assessment will lead all honorable experts to the same conclusions. Often it is assumed that the non-technical concerns of the lay public (fairness, local control, courtesy, property values and moral values to name a few) are irrelevant or of secondary concern and that therefore risk communication can be one-dimensional and technical instead of being (more realistically) multidimensional and value laden.

C. <u>Uncertainties and Non-technical Considerations</u>

Among the numerous technical and non-technical factors that need to be considered by the risk manager are the number and age of the exposed population. If the location of concern contains low income housing, school yards, or playgrounds, the issue is far more significant than if the area of concern contains factories, retirement communities or warehouses. The decision maker needs to consider present and probable future land use in deciding whether to act and if so what kind of remedial effort is required.

It is also important to recognize the probabilistic nature of this problem. While it is possible that 300 ppm lead in a soil may present a health problem to some children, it is more likely that 1500 ppm will present a problem. Numerous factors such as the precentage of bare soil present; the number, age and ethnicity of the children; and the social-economic status of the residents determine the extent of the problem. There are many areas that have soil leads greater than 1000 ppm. It is important to begin cleaning up the largest number of areas containing the high risk children <u>and</u> the highest lead contamination. These are mostly the inner cities where soil leads are high because of the past use of lead-based paint and leaded gasoline coupled with more low income minority children.

While the bulk of this document concerns itself with scientific and technical issues, it is clear that many legal, political, social and economic aspects are important factors. Indeed, in many cases, these will be the deciding factors on remedial actions.

There is always uncertainty in the scientific and technical data and models. This uncertainty will leave the decision maker (risk manager) without an absolutely accurate assessment of the risk. In many cases, the uncertainty will be so great that policy decisions regarding the appropriate margin of safety, the feasibility remediation and the ultimate cost of clean-up will be the over-riding factors in the decision. In these cases risk communication will play an even more important part in the process than usual.

1. Geographic and Physical Processes that Affect Soil Lead Accumulation

Thorough understanding of the fundamental mechanisms involved in soil accumulations of lead assist in describing the relationship between various types of lead sources and the responses of the population to these sources. The strong relationship between blood lead and soil lead has been well-described for a number of different populations living in a variety of socio-economic conditions. The most at risk populations show the strongest relationship, but the relationship is strong even for the least exposed middle to upper middle class children living in a suburban situation (Rabinovitch and Bellinger 1988). There are several key features that assist with understanding the geographic distribution of lead in soil.

a. Rural Background Lead

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The lead content of unmineralized soils is well below 150 ppm within the rural setting. In the U.S., a major survey of rural soils revealed a geometric mean of less that 20 ppm. In studies where special efforts were made to collect soil samples which were insolated from highways, industries and other sources of lead, the lead content measured 5 to 10 ppm and even lower. In mineralized soils, the background levels of natural soil is around 150 ppm. Against this background lead there are various types of lead sources that have caused the accumulation of lead. See Table 14.

The two major sources of lead (excluding its use as an insecticide) that have accumulated in the urban environment have been derived either from paint or emitted as an aerosol from smoke stacks or automobile exhaust and become deposited into the soil. Figure 3 illustrates the history of lead usage from 1910 to 1989.

Soil that has been contaminated with paint was either within close proximity to a painted surface that has deteriorated, or secondarily, polluted from the disposal of materials (wood and metal) that was covered by leaded paint. Soil contaminated by aerosols, as described below, have become dispersed in a far more complex manner. The aerosol sources will be described in terms of the geographic patterns of lead accumulation that they impose upon the environment. There are three types of aerosol sources of lead that can be described in terms of their geographic characteristics, (1) point sources (2) linear sources and (3) area sources.

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Table 14

Distribution of lead contents of soils from England, Wales, and the United States

	Data Source*		
Percentile	Wales(654)+	England(1774)	U.S.(3305)++
	------------------------mg kg^{-1}-----------		
0.1	1.3	5	0.2
10	13	12	-
50	34	45	11
95	211	168	26
99.4	3,369	16,400	4,109

*Number of samples appears in parentheses.

+Collected from sites on a regular 5-km grid over all of Wales and all of England.

++Collected from major crop producing regions on sites removed from point and mobile sources of contamination.

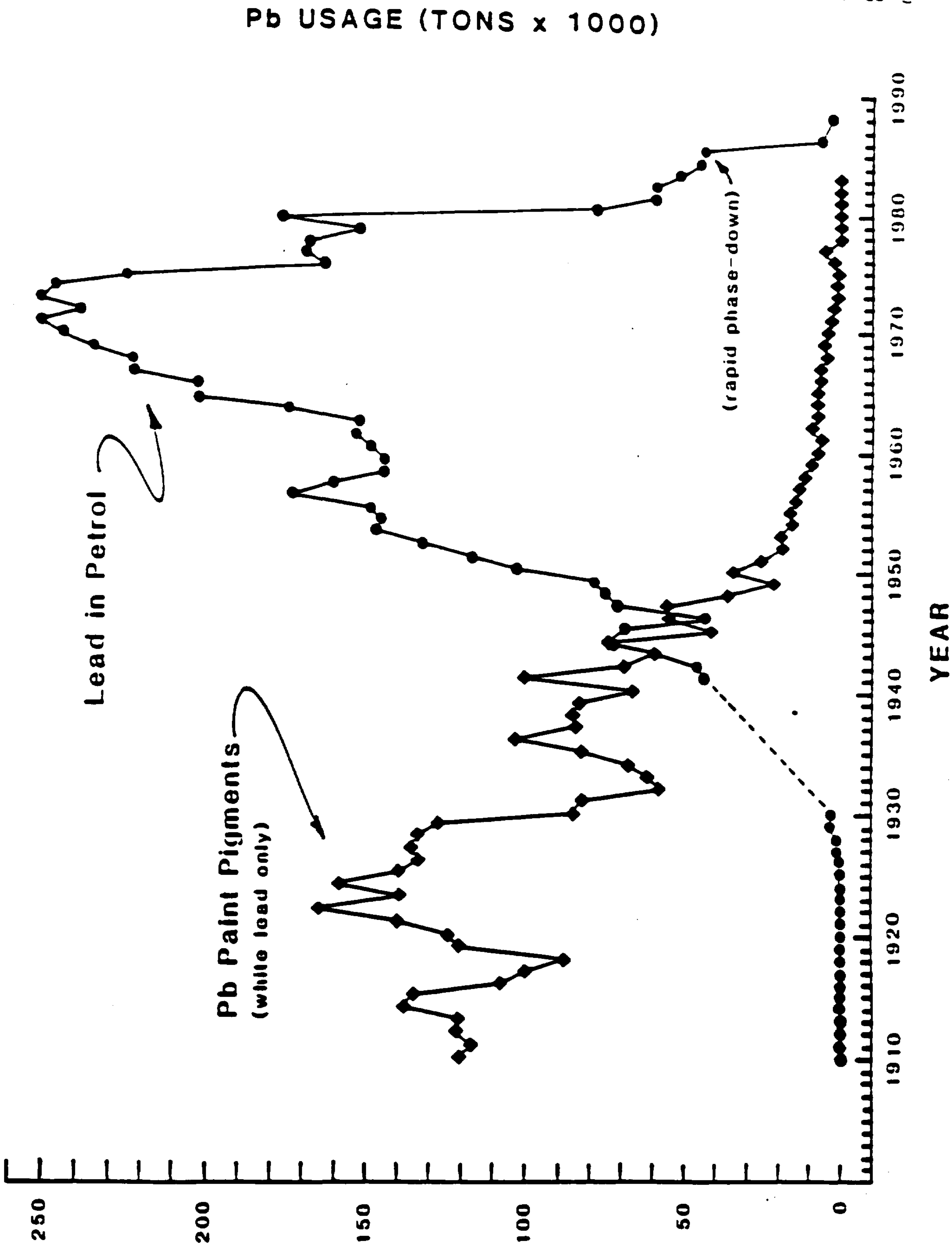

Figure 3: Lead Usage from 1910-1989

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b. Point Sources

The Point Source delivers lead into the environment from a single site. A smoke stack of a primary lead smelter may be an example of a point source. The pattern of lead distribution around a smoke stack is influenced by two main features, (a) the physical characteristics of the lead particles as they are emitted from the smoke stack and (b) the stack height and prevailing meteorological conditions which carry the emitted particles and disperse them across the landscape. The distribution of lead around point sources is well known. The lead concentrations are highest near a point source and decrease as a log function of distance away from the source. There are several phenomena operating to cause the rapid decrease with distance. For example, particle size is very important. Large particles tent to fall out relatively quickly and smaller particles become entrained in the air stream and can be carried great distances. Also, the geometry of dispersion is important. As distance increases from a point source, area increases at a geometric rate. This process also results in the dilution of lead particles in a manner that is a function of distance. The pattern of lead accumulation resulting from the above processes is a series of more or less concentric rings with concentration decreasing away from the point source.

c. Line Sources

When a point is moved across a plane it forms a line. The Line Source of lead is associated with automobile emissions and traffic flows. Lead emissions from automobiles resulted from the

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use of lead as an octane booster in gasoline. Until recently, many thousands of tons of lead were used as an additive to gasoline each year. U. S. use peaked at over 200,000 metric tons per year in 1970. Many studies have been conducted on the lead distribution pattern associated with highways. Lead accumulations are highest along busy highways and lowest along infrequently traveled roads. As with point sources, in a rural area there is a rapid decrease of lead with increasing distance from the highway.

Because of the amount of lead used which may be accumulated as dust, the gasoline source is especially important to consider in detail. About 75% of the lead added to gasoline was emitted from the exhaust pipe and the remaining lead was deposited in the oil or in the muffler and tail pipe of the exhaust system. About half of the lead is contained in particles of sufficient mass that are deposited within several tens of meters from the highway. The other half of the lead emitted as exhaust is contained in very fine particles that may become entrained in air. The entrained aerosol particles are then removed from the atmosphere through washout, deposition and impaction. Lead aerosols are widely dispersed. Some portion is deposited in sediment basins and glacial ice at remote places. Impaction explains the occurrence of lead on tree limbs and leaves even in the most remote areas. Impaction takes place on any verticle surface. Although lead in gasoline has been dramatically reduced in recent years in the U.S. and other industrialized nations, the accumulation of lead along highways remains as a legacy of the use of lead as an additive to gasoline during the past 50 years or so.

d. Area Sources

When a line is moved perpendicularly across a plane it demarks an area. There are no true primary Area Sources of lead. However, waste dumps created from mill tailings (the material left over from the concentration of ores extracted by mining) and other secondary area sources are examples of this type. This material can be dispersed by wind and water erosion. Often the sandy nature of tailings material make these waste piles attractive recreation areas for dirt biking and other activities that bring children in contact with the contaminated material.

The modern industrial city is composed of a complex combination of point sources and linear sources of lead which are unevenly spread over an area. The uneven distribution causes the lead content of urban soils to have a very distinctive pattern. Large cities have more accumulated lead than small towns of the same age. Within a given city, the amount of lead that has accumulated is usually highest in the neighborhoods near the center of the city and lowest in outlying neighborhoods. This pattern holds up even when the ages of the neighborhoods are similar. Old neighborhoods in outlying areas have significantly lower amounts of lead than similar aged neighborhoods located toward the center of the same city.

The basic patterns of soil lead in various urban environments match those described for the lead exposure of the population. The congruence between the soil lead and blood lead matches what has been learned about the relationship between soil lead and blood lead for children. The congruence between soil as an environmental measure and the exposure response by childhood populations provides planners and policy makers with an important tool for defining critical sites, and for setting priorities for undertaking cost efficient amelioration of excessive lead exposure of children.

2. Uncertainties

It should be clear from the above discussion that the patterns of lead are very complex within the urban environment. What is known is that soil lead and blood lead are strongly related. But is also known that the increase of blood lead per increase in the content of lead in soil varies for different populations. The least exposed cleaner and well-maintained environments, experience a small increase per increment increase of lead in soil (less than 1 µg/dl / 1000 ppm soil for the least exposed upper middle class suburban children according to Rabinovitch and Bellinger, 1988). The most exposed children exhibit a larger increase in blood lead per increment increase in lead in soil. Several studies have found levels of about 5-10 µg/dl / 1000 ppm (Angle and McIntyre 1982, Bornchein, et al 1986, Brunekrief, et al 1983) for the most exposed children. The greater sensitivity of the most exposed children is probably a function of the poor conditions of the environment (bare soils and play areas next to buildings), low nutritional status (especially low calcium and iron status), and perhaps an overall difficulty with supervision in a lead contaminated environment.

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It has been observed that the most exposed children have behavioral characteristics that make them hard to discipline. Their lead exposure predisposes them to lower quality of parental supervision (Dieterich et al 1987).

The major uncertainty is how to proceed with amelioration. The above information provides some important guidance as to what can be done. Given the different rates of exposure in different places (ie, the inner-city has a greater rate of exposure than suburban or rural areas) it should be clear that by focusing attention on those urban places that have the greatest content of lead will provide the largest amelioration benefit per unit expense of cleanup cost. Mapping the soil lead levels in the countryside and major cities (Davis et al 1984, and Mielke et al 1989) can delineate those areas of greatest and immediate concern. There are many uncertainties concerning how to proceed with lead prevention. For example, deleading homes seemed like a good idea. But, because of the dust it generates, without thorough cleanup afterward, it is not effective in preventing lead exposure to populations of young children. Demonstration programs are needed to develop and test lead exposure prevention methods. There are several methods that should assist children. For example, if small particles are a major component of the problem, then the use of high efficiency vacuum cleaners (ULPA and HEPA) should reduce lead burdens from dust accumulations in homes of neighborhoods with the highest lead content; improving the nutrition of the children who are most exposed should reduce their physiological response to lead. These approaches would be relatively inexpensive. Some of the most contaminated urban neighborhoods may need out-right soil removal and replacement in order to reduce the risk of lead exposure from soil and dust to acceptable levels. Other places may only need some resodding or grass seed in order to reduce lead levels to acceptable levels. Most non inner-city and small town neighborhoods probably to not need any work at all.

All people should benefit from carefully prepared and well-focused education about the lead problem. But herein lies a problem. The needs of a neighborhood must be matched to the reality of the fact that there is not simply a single lead problem, rather there is a multi-dimensional lead problem. The problem is further confounded by the divergent cultural makeup of society and the complicated environmental lead patterns of the neighborhoods of our modern urban society. Solving the lead exposure problem requires a number of approaches. It is important to be able to determine what methods are most effective as options for various types of neighborhoods as lead prevention becomes part of public programs.

3. Behavioral/Social Aspects of Lead Poisoning

The principal concern with respect to dust/soil lead is the young (6-72 months) child who inadvertently (or purposefully) ingests contaminated dust and/or soil. Clearly there are many social/economic/behavioral parameters that can increase the extent of exposure through hand-to-mouth activity in the child. These include the degree of cleanliness of the environment, the frequency of hand-to-mouth activity, the extent of parental supervision, the extent of contamination, and the extent to which absorption can be affected by factors such as nutritional status.

While much remains to be understood about these interactions, there is a considerable amount of information available that gives insight on this complicated problem.

a. Social/Economic Characteristics as Factors in Risk

A recent study by Pope(1986) estimates that the percentages of housing by year of construction having paint with lead greater than or equal to 0.7 mg/cm^2 as: pre-1940, 99%; 1940-1959, 70%; and 1960-1975, 20%. Of particular interest are those homes containing lead-based paint which are not in good repair. Chisholm, et al. (1985) and Clark, et al. (1986) have shown that deteriorated housing has a very significant effect (as much as a doubling) on blood lead levels in young children. Clearly, deteriorated older housing stock will tend to be located in the poorer areas of the central cities.

The expectation of greater lead exposure to lower SES (Social Economic Status) children is supported by the NHANES II survey (1982) which found that the prevalence of blood lead levels greater than 30 μg/dl in 6 to 60 month old children in families with an annual income less than $6000 was nearly 10 times higher in families with an annual income greater than $15,000. Other investigators such as Bornschein, et al.(1985) have demonstrated the influence of educational background and degree of parental care on childhood blood lead levels.

It is quite likely that several factors contribute to the increased exposure of poor children to lead. Not only is there a

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higher incidence of dilapidated older housing, but there is also a tendency to find low income housing areas near busy central city streets(Mielke, et.al., 1985) and there is a higher incidence of nutritional deficiencies that are associated with increased lead absorption by children.(Yip, et.al., 1981) In addition, factors such as an increased incidence of working single parents and accompanying poorer supervision because of poorer access to day care may contribute to the greater risk to low-income children. Occupations of adults can also result in added exposure of children to lead. For example, contaminations of the home can occur from adults with lead dust on their clothing from lead related jobs.(NAS, 1980, Rice, et al., 1978)

b. Ethnicity as a Risk Factor

The NHANES II data also exhibited a dramatic difference in lead exposure between white and black children. The rate of exposure of black children is 2-4 times greater than white children between 6 and 60 months of age at blood leads over 30 μg/dl. The situation for Hispanic children is less clear because the NHANES II data could not distinguish this group. A survey in New York found that Hispanic children were intermediate to white (Anglo) and black children in blood lead concentration. (Biilick, et al., 1979)

Because the NHANES II survey was not designed to distinguish Hispanics from Anglos and blacks, the Hispanic Health and Nutrition Examination Survey (NHANES) was conducted in 1982 to 1984. (Carter, et al., 1989) This survey distinguished children of Mexican-American ancestry from those of Puerto Rican and Cuban ancestry. It also distinguished children of Mexican-American ancestry born in Mexico from those not born in Mexico. Unfortunately, because of the downward trend of blood lead levels (ATSDR, 1988) it is not possible to compare these groups with Anglos and blacks, but they can be compared to each other. In general, Puerto Rican children living in New York were at greater risk than the other subpopulations. Mexican-American children born in Mexico were found to have higher blood lead levels than those born in the U.S.

Various social-economic indicators were also found to be significant in the HISPANIC NHANES study. Mean blood lead levels for Mexican-American and Puerto Rican children were highest for those children living in the central cities in families with the lowest annual incomes and education of head of household. Puerto Rican children living with a married head of household had lower mean blood lead levels than did children living with a single head of household.

It is possible that the ethnic background is simply a surrogate for a number of social/economic/cultural factors. The high proportion of Puerto Ricans who live in poverty (42%) may be the driving factor that contributes the exposure through a combination of intercity neighborhoods, old dilapidated housing, poor nutrition, inadequate supervision (lack of day-care, etc.) and other factors that can be attributed to poverty. In the same regard, Mexican-American children living in the Southwest have a 23% poverty rate compared to only 11% for all persons of non-Hispanic origin.

Thus, screening, investigation and remedial programs should focus first on areas in the central cities with high populations of black and Puerto Rican children.

c. Age Distribution

Numerous studies have shown that urban children, particularly those of pre-school age (less than 5 years) are the sub-population most at risk (Mahaffey, 1982, Carter, 1989, ATSDR, 1988). As noted by the ATSOR report (1989), the precise age interval for children at greatest risk has not been defined. Because the exposure begins prenatally there is, in general, not a lower bound on the age. Since this report, concentrates on lead in dust and soil, it seems reasonable to assume that infants and toddlers will be a greatest risk from contaminated soils and dusts. The NHANES II study showed that 6 to 24 month old children had higher blood lead levels than 36 to 60 month children who in turn had higher blood lead levels than those older than 60 months.

d. Gender

The NHANES II study found that the percentage of elevated blood lead levels was slightly higher among boys than girls but this difference was not significant (Mahaffey, et al 1982). In the HISPANIC NHANES study Mexican-American males had a statistically significantly higher mean blood lead level and a nonstatistically significantly higher percent elevated blood lead than did Mexican-American females (Carter, et al 1989).

At this point there does not seem to be a strong reason to include gender as a risk factor.

e. Customs and Mores

In the Mexican-Hispanic and Hmong Cultures, folk remedies are often the cause of high blood lead levels and lead poisoning in children. Azaran and greta are fine powders with total lead contents varying from 70% to greater than 90%. They are often used by Mexican-Hispanics to treat children under 12 years of age for gastrointestinal illness. Hmong parents use a folk remedy referred to as "pay-loo-ah" to treat infants and children for rash and fevers. The remedy consists of red and orange powders with a lead concentration of 8%. Although there have been extensive educational programs directed towards Hispanic and Hmong families publicizing the dangers of these folk remedies, customs of use may still be retained in certain families and should be taken into consideration in any type of study or assessment (MMWR, 1983, MMWR, 1983a).

f. Educational Background

Presumably, the educational background of concern is that of the parents. Because this is highly correlated with, and part of, social-economic status, there is an overlap with the discussion in Paragraph 1 of this section. The NHANES II results do not give any insight on the importance of parental education. The HISPANIC NHANES (Carter, et. al, 1988) data did show a significantly lower blood lead for Mexican-American children whose parents had a higher level of education.

Since this factor interacts strongly with those involved in Social-Economics factors there does not seem to be a strong reason for considering it separately.

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4. Legal Aspects

a. Currently, there is not a national policy for cleanup of lead in soil.

1) EPA has established no reference dose (RFD), or other level, setting an acceptable daily intake for lead. Accordingly, the various EPA regions experience great difficulty in completing risk assessments for lead-contaminated sites.

2) In the absence of a national standard, EPA regions reach inconsistent decisions on appropriate cleanup levels.

3) The EPA Office of Solid Waste & Emergency Response (OSWER) currently advises the regions to use the Centers for Disease Control (CDC) guidance of 500 to 1000 parts per million for cleanup decisions. (*Inside EPA*, Jan. 20, 1989, p. 15).

b. **Other lead levels have been established, and may be considered during remedial activity.**

1) Occupational Safety and Health Act (OSHA) Air Contaminant Levels.

a) Action level - 30 $\mu g/m^3$ (averaged over an 8-hour period).

b) Permissible Exposure Limit (PEL) - 50 $\mu g/m^3$ (averaged over an 8-hour period).

c) OSHA is designed to protect workers in a closed environment (e.g., a building).

2) Clean Air Act (CAA).

a) National primary and secondary ambient air quality standards for lead: 1.5 $\mu g/m^3$ (maximum arithmetic mean averaged over a calendar quarter).

b) Different emission limitations can be placed on each source of air pollution. (see e.g., 40 CFR Part 60).

c) States may adopt additional and more stringent limitations.

3) Clean water act (CWA).

a) National Primary Drinking Water Regulations (Maximum Contaminant Levels - MCLs): 0.05 mg/l for lead.

b) On August 18, 1988, EPA proposed regulations which would place the MCL for lead at 0.005 mg/l, and the MCL goal (MCLG) at zero.

c) Differenc effluent limitations can be placed on each source of discharge into waters of the United States. (See, e.g., 40 CFR Part 433).

d) States may adopt additional and more stringent standards.

5. <u>Cleanup Levels for Lead</u>

The EPA has not established a reference dose (RfD), or other level, which would set an acceptable daily intake for lead. As a result, the various EPA regions have experienced great difficulty in completing risk assessments for lead-contaminated sites. The absence of a national standard has resulted in inconsistent decisions on appropriate cleanup levels from the different EPA regions. This inconsistency has prompted the EPA's Office of Solid Waste and Emergency Response (OSWER) to advise the regions

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to use the Centers for Disease Control (CDC) guidance of 500 to 1000 parts per million for cleanup decisions (Inside EPA, Jan. 20, 1989, p. 15).

Although there is as of yet no national policy, other lead levels have been established and may be considered during remedial activities.

The Occupational Safety and Health Act (OSHA) Air Contaminant Levels were designed to protect workers in closed environments such as buildings. OSHA has set an Action level at 30 $\mu g/m^3$ (averaged over an 8-hour period), and a Permissible Exposure Limit (PEL) of 50 $\mu g/m^3$ also averaged over an 8-hour period.

The Clean Air Act (CAA) has set a national primary and secondary ambient air quality standards for lead at 1.5 $\mu g/m^3$ with the maximum arithmetic mean averaged over a calendar quarter ("ambient air" is the portion of the atmosphere, external to buildings, to which the general public has access). The CAA allows for different emission limitations to be placed on each source of air pollution (see e.g. 40CFR Part 60). The Clean Air Act also stipulates that individual states may adopt additional and more stringent limitations.

The Clean Water Act (CWA) has set National Primary Drinking Water Regulations (Maximum Contaminant Levels - MCLs) at 0.05 mg/l for lead. However, on August 18, 1988, the EPA proposed regulations which would place the MCL for lead at 0.005 mg/l, and the MCL goal (MCLG) at zero. The CWA allows for different effluent limitations to be placed on each source of discharge

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into waters in the United States (see e.g. 40 CFR Part 433). The Clean Water Act also enables individual states to adopt additional and more stringent standards.

6. <u>Potential Liability in Establishing Cleanup Levels</u>

A small risk of liability exists if a person is injured at a "cleaned up" lead-contaminated site, and that injury can be traced to excessive lead concentrations remaining in the soil. However, the lawsuit potential can be reduced if a few precautions are taken. To begin with, the most likely basis of action is negligence, defined as "...the failure to observe, for the protection of the interests of another person, that degree of care, precaution, and vigilance which the circumstances justly demand, whereby such other person suffers injury." Therefore, the responsible party should make every attempt to assimilate all available studies and make an informed, scientific judgement based on those findings. This will insure that the responsible party is utilizing "due care" in the determination. The investigation may find that "safe" lead levels will vary among contaminated sites, due to the differences in exposure potentials. This fact, and any other limiting data, should be included with the recommendations, so as to appropriately limit the scope of the findings.

A negligence cause of action would require a finding that the responsible party owed some duty to the suing party. This may be difficult to establish if: (1) no specific site is contemplated in establishing the guidelines, and (2) the

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recommendations emphasize that the necessary cleanup level may vary with each site, depending on potential exposures.

It should be noted that EPA and the States, under the current regulatory scheme, have the final authority to determine appropriate remedial levels. This determination - the Record of Decision (ROD) - must be made at each site. In addition, each ROD is published for public review and comment. By vesting final authority in the government, the process greatly reduces the liklihood that the responsible party would be held liable for excessive lead levels remaining after the remediation.

The most likely target of any lawsuit would be the government agency approving the cleanup level, and the parties who are responsible for the original contamination and/or subsequent cleanup of the site.

7. Economic Considerations in Establishing Lead Levels

After the remedial investigation (RI) is completed, a feasibility study (FS) is undertaken to develop and evaluate the remedial alternatives available at a particular site. Cost is considered at both the initial screening and detailed analysis stages of evaluation. Thus, during the initial screening of all alternatives developed in the FS, the cost of implementing the remedial action must be considered which includes the operation and maintenance costs. An alternative which far exceeds the costs of other alternatives, without providing a substantially greater measure of protection to the public's health or the environment, nor increased technical reliability, should be excluded from further consideration. Those alternatives which

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meet or exceed the appropriate Federal public health and environmental requirements (ARARs), are more desirable since they will provide greater protection than do those alternatives which do not meet such requirements.

After the initial screening, the remaining alternatives are evaluated in detail and the lead agency will select a "cost-effective remedial alternative" that properly mitigates and minimizes threats to human health and the environment. In choosing the appropriate alternative, the lead agency will consider "cost, technology, reliability," and other concerns, with regards to their relevant effects. Also, the lead agency will typically consider costs only among those plans which meet the designated ARARs, although there are some statutory exemptions.

Cost-benefit analysis is made on a case-by-case basis. There is currently no set formula or ratio to apply in determining what degree of cleanup, due to excessive cost, would be viewed as inefficient.

EPA proposed revisions to the National Contingency Plan (NCP) on December 21, 1988. Cost effectiveness is still to be considered in selecting a remedy, but only after the alternatives have been found to provide adequate protection of human health and the environment. The selected alternative must also comply with all designated ARARs, or provide grounds for invoking a waiver of an ARAR.

8. <u>Economic and Financial Considerations Concerning Remedial Actions</u>

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Before determining the need for a remedial action, it is necessary to establish a scope of the available financial resources. Depending on the site's location, size, and uses, the contaminated site may be eligible to enlist community, state and federal resources to supplement private funds, thus, ensuring that all necessary cleanup actions may be taken.

The costs involved with the physical cleanup of the soil are not always the only ones incurred during a remedial action. Liabilities involved in taking or not taking action also play a significant role in determining the scope of the remedial action plan. The costs of monitoring a site after the cleanup has been completed should also be factored into the total cost of the remedial action.

Remedial action methods which require some form of soil treatment to reduce potential health risks include, but are not exclusive to, the following:

a. Soil Removal

As the name suggests, this method involves excavating all of the lead contaminated soil and transporting it to an approved site for disposal. Clean fill is brought in, where it is necessary, to replace the soil excavated at the contaminated site.

This method is sufficient for most sites and serves as one of the quickest measures to immediately reduce the threat to public health. However, if the volume of contaminated soil requiring excavation is large, this method can be extremely costly. Another important point to remember is that the soil excavated from the site has not been decontaminated, but simply moved to another location and so it still contains unacceptable levels of the contaminating substance. (ICRCL 1987)

b. Soil Containment

Soil containment isolates the contaminated soil by covering it with new, clean soil or a hard cover. Hard cover is the preferred and more cost effective method of covering; however, to ensure that it works appropriately it must be well designed and properly installed and maintained. (ICRCL 1987)

A clean inert fill can be used so long as it is sufficiently thick to contain the contaminated material and results in a soil which has an acceptable lead concentration. This process should not mix the old contaminated soil with the new covering soil and ground cover should be reintroduced as soon as possible to prevent new soil erosion. (Elias 1988)

c. Contaminant Extraction: Soil Washing and Flushing

These methods involve chemically treating the contaminated soil and, while they are effective at removing metals, they can be quite costly. (ICRCL 1987)

To wash contaminated soil, it is excavated and mixed on-site with a chemical capable of removing lead. The liquid is then extracted and the clean soil returned to the site. The chemical-lead extraction fluid can be treated and the lead removed for re-use at another site. (Elias 1988)

Soil flushing is a technique which can be used when a contaminant has already reached the ground water. The process is applied directly to the soil's surface. The solution is then given time to reach the groundwater. Once that has occurred, the groundwater is pumped up to the surface and treated. The clean groundwater is then reapplied to the soil surface. (Elias 1988)

This method is cost-effective since it eliminates soil removal and replacement costs; however, it may require several applications before the contaminants are removed. Furthermore, soil flushing is not a closed, contained process and, therefore, runs the risk of further contaminating the groundwater. Methods of modified soil flushing which are more controlled and contained have also been suggested and may prove useful in solving present limitations. (Elias 1988)

d. <u>Deep Tilling</u>

Instead of removing, covering or treating the contaminated soil, it can be tilled. Tilling mixes the contaminated soil with clean sub-soil, thereby reducing the lead levels on the surface. (ICRCL 1987) Tilling potentially reduces costs by eliminating the need for excavation and disposal; however, new costs may be incurred controlling drainage or erosion problems which may result. (Elias 1988)

e. <u>Other Methods and Further Considerations</u>

Revegetation of bare soils, community education, behavior modification, zoning, and vacuuming of dust within the house should all be considered as other methods of remedial action. The costs of these actions vary depending on the size of the population and the site itself.

After remediation has been completed, the site must be monitored to ensure the cleanup action remains effective. The

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scale, duration, and cost of monitoring depends on the type of action taken. Finally, with time, the action should be assessed for future reference.

f. Costs of Not Doing Anything

The costs of undertaking a lead prevention project that is designed to reduce lead exposure is an expensive undertaking. Can society bear the cost of cleanup? Considering that lead paint removal and soil replacement costs thousands of dollars per home, the costs seem too much to bear. It is the intent of this section to consider some of the medical and remedial costs of lead exposure so that the price of not doing anything can be placed in perspective.

The costs of excessive lead exposure are only partially quantifiable. For example, the costs to society of permanently limiting the potential of a child cannot be known. What can be known are some of the treatment and remedial costs associated with the most extreme forms of lead exposure.

An evaluation of some of the costs of lead poisoning were undertaken by Povenzano, 1980, the EPA 1985, and Szako and Pollack, 1987. The later document provides estimated costs for the average medical and remedial education costs attributable to child lead poisoning in Massachusetts. In 1986, the estimated average medical cost is $2,400 and estimated cost of remedial education is $3,100 per lead poisoned child in Massachusetts. At $5,500 per lead poisoned child, in Massachusetts about $11 million is spent for the 2000 new lead poisoning cases which are found each year.

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It is important to underscore what the above costs do not include. They do not include speech, physical and occupational therapy needed for many of these children. They do not include the extra costs in education (national average of about $5,000 per pupil per year) for repeating grades in school that are often required by these children. The above costs do not include those incurred by a far larger group of children who may be experiencing adverse effects as a result of other levels of lead exposure. For example, exposure levels of 15 μg/dl and even lower are now recognized as being associated with learning and behavioral deficits and the costs of assisting this group of children are not included in the above costs. The costs incurred as a result of excessive lead exposure are so large that there are enormous benefits to society for expending efforts to prevent this problem.

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SUPPLEMENT I

RECOMMENDED METHODS FOR SOIL SAMPLING FOLLOWING PROPOSED INTERNATIONAL STANDARD

INTRODUCTION

Soil is the uppermost layer of the Earth's crust, composed of solid particles and usually containing either or both water and air in the pore space. The topsoil often contains organic matter and microorganisms and is a possible plant site. The soil lying directly above the unweathered rock or sediment material is called solum.

In the context of soil protection the following should also be considered as belonging to the soil:

- underground
- raw material deposits
- anthropogenically influenced soil
- special defined areas (e.g. building areas, areas reserved for traffic, leisure and recreational areas, fallow land) (taken from ISO...)

Depending on its composition, structure and usage a soil may accumulate contaminants.

Contaminants are transported into the soil via air and water or as a liquid or solid input.

Adverse effects to natural soils may arise if the release into the soil or the level of secondary changes of substances in the soil is greater than the capacity of the soil to decompose the polluting substances, or if the material input is greater than the output. Natural background values may cause significant preconcentrations.

Soil may accumulate, change or shift contaminants for years and even may release them again.

Depending on the type of soil higher concentrations of substances, natural or contaminant, may need be taken into consideration. It is known for the heavy metals that they may show higher concentrations related to clay content or soil organic matter.

It is important to monitor both background and increased values.

A. Exploration strategy

1. Scope

This international Standard sets out the general principles to be applied in drafting sampling programs aimed at quality control, quality characterization, and identification of sources soil pollution. Detailed instructions for specific sampling situations will be given in subsequent International Standards.

Sampling of soil material aims at obtaining material of representative composition for analytical determinations.

In agreement with the investigating laboratory sampling has to be adjusted to the aims of the survey (physical, chemical or biological) or to other requirements (e.g. layers, mapping of lateral profiles, quality tests, investigation by labs).

Since the quality and value of the analytical testing results will depend upon the accuracy of the smapling, it is necessary that the samples collected should be reliable and representative of their particular location. This will necessitate that a great deal of care is exercised in determining where and how samples are collected.

2. Fundamentals of Optimization

Design of the sampling grid and number of sampling points should be optimal with respect to technical and financial considerations.

During the initial stage and particularly in the case of possible contamination, the following points should be dealt with systematically and be monitored:

- the type and nature of expected contamination
- knowledge of processes or possible sources of contamination
- available data on the area (geologic and hydrologic situation,kind of use)
- mapping of the area (including future development)

These data will serve as a basis for an optimal sampling strategy in order to:

- determine the nature of the contamination
- reconstruct the distribution pattern of concentrations in the soil
- localize the source of contamination
- qualify and quantify manner and degrees of accumulation and the bonding of contaminants in the soil, or of their release into the environment (air, groundwater, plants, animal, man)
- determine ~~in~~ soil quality in general

3. Preliminary Investigation

This should cover the following points:

Geographic References

- state
- district
- municipality
- Census tract (U.S.)
- street (road, drive, etc.)
- x-coordinate
- y-coordinate
- altitude
- dimensions
- land utilization
- land register number
- legal position, ownership

Situation at the area to be investigated

- pre-sampling, special kinds of utilization and permits
- infra-structure, future reclamation
- canalization, drainage systems, surface runoff
- position of water tables
- slope and exposition
- population and size of city

In suspect areas

- basic (raw) materials, chemical, products
- waste materials
- period of production
- hazards, accidents
- manners of waste disposal
- permits
- highway density and traffic congestion
- inner city locations

4. Inventory of the Local Situation

This should be carried out by qualified personnel with experience of the type of site to be investigated.

Start by visiting the site.

The following documents may be helpful:

- topographic maps
- population map
- highway map
- geological and pedological maps from geological surveys
- maps of soil use

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- hydrological maps
- geochemical maps
- reference list of background values
- plant ecology maps
- aerial photographs and satellite imagery
- historical information like:
  - statements from employees
  - statements from (ex)neighbours
  - history of growth of city
  - statements from drivers of waste transports
  - drop out rates of high school children

Preliminary mapping of the specific situation serves as a base to delineate the area to be investigated as well as to estimate the possible distribution of potential sources of contamination such as places of specific production processes, waste dumps.

In addition, information on the general distribution (horizontally and vertically) of soil types, soil profiles and changes in their distribution should be collected at this stage (e.g. refer to geological survey or soil maps).

5. <u>Sampling Pattern Techniques</u>

<u>General</u>

The choice of sampling pattern will depend on the results of the preliminary, and also on the degree of homogenity of the soil at the location of sampling.

<u>Techniques</u>

All pattern techniques are based upon the selection of sampling points. Information in between these sampling points is gained by interpolation. The degree of certainty of information will depend upon distance between the sampling points. The following examples demonstrate some established methods applied for an unbiased positioning of sampling sites.

a. <u>Irregular Sampling and Circular Grids</u>
   Figure 4 illustrates a circular grid used for the survey of support areas.

b. <u>Systematic Sampling (Regular Grids)</u>

In many cases a regular grid is selected. Because there is a direct relationship between optimal distance between sampling points and the (estimated) dimension of the contamination (see preliminary investigation), spacing between sampling sites should not exceed the greatest (estimated) extent of the contamination.

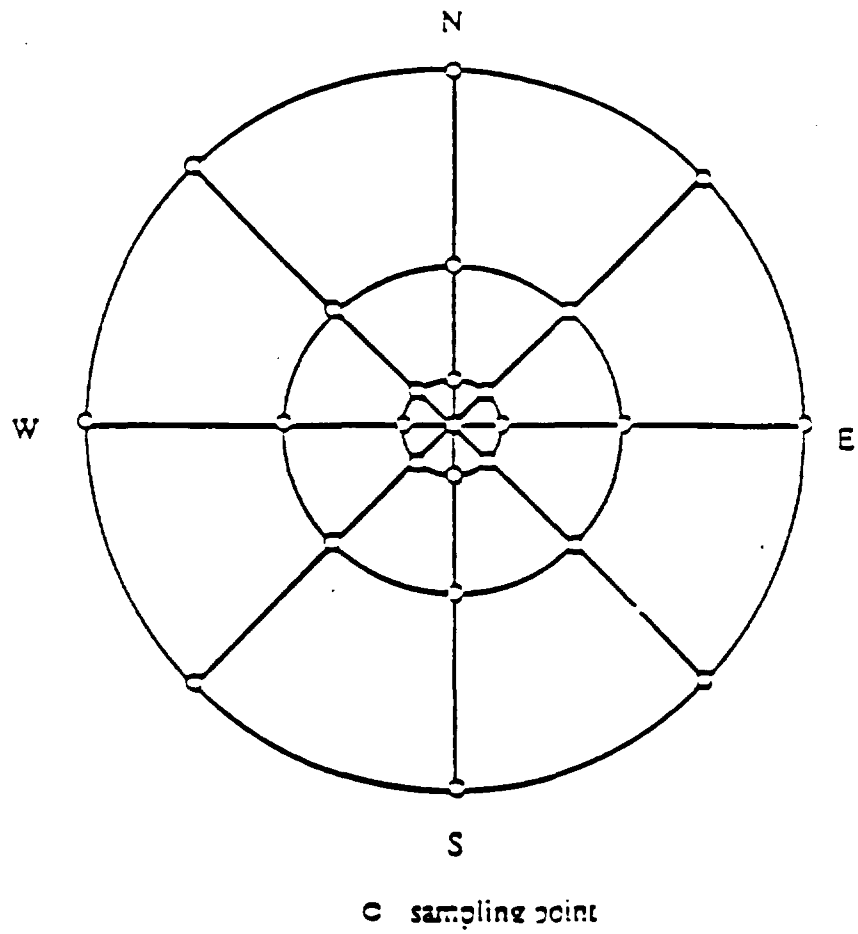

Figure 4: Circular Grid for the Survey of Suspect Areas

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Grid dimensions will depend on how detailed the information has to be. The assigned spacing will differ according to purpose e.g. whether the aim is to collect samples of average degree of contamination, or the localization of isolated sources of contamination or to establish the extent of contaminated areas (horizontal) or zones (verticle). The latter attains particular importance in cases where a contamination is already located and a follow-up sampling program becomes necessary (Fig. 5).

Considering the pros and cons of a regular grid, it is an advantage that it may be set up easily and grid dimensions readily varied (Fig.6).

c. Random Sampling

In cases of presumably spasmodic occurences of contaminated zones random sampling could be applied. Sampling points within the area are selected by using random numbers which may be found in tables included in manuals on statistics or which may be generated. This technique has the disadvantage of irregular coverage and makes interpolation between sampling points difficult (Fig. 7).

d. Stratified Random Sampling

This method will avoid some disadvantages of random sampling. The site is divided into a number of grid cells, and a given number of randomly distributed sampling points is chosen each cell. The method has disadvantages in terms of interpolation. (Figure 8)

e. Unaligned Random Sampling

The term "unaligned" means "irregular" in the sense of "not-in-a-line".

This method is in keeping with stratified random sampling, but in this case only one of two coordinates is being chosen at random.

The procedure is as follows:

Example: Given a grid with 24 cells (squares), arranged in 4 lines and 6 columns (Fig. 9).

(1) For the first cell (line 1, row 1) x- and y-coordinates are chosen at random.

(2) For cells 2,3,4,5 and 6 only the y-coordinates are chosen at random.

(3) For cells 7,13 and 19 only the x-coordinates are chosen at random.

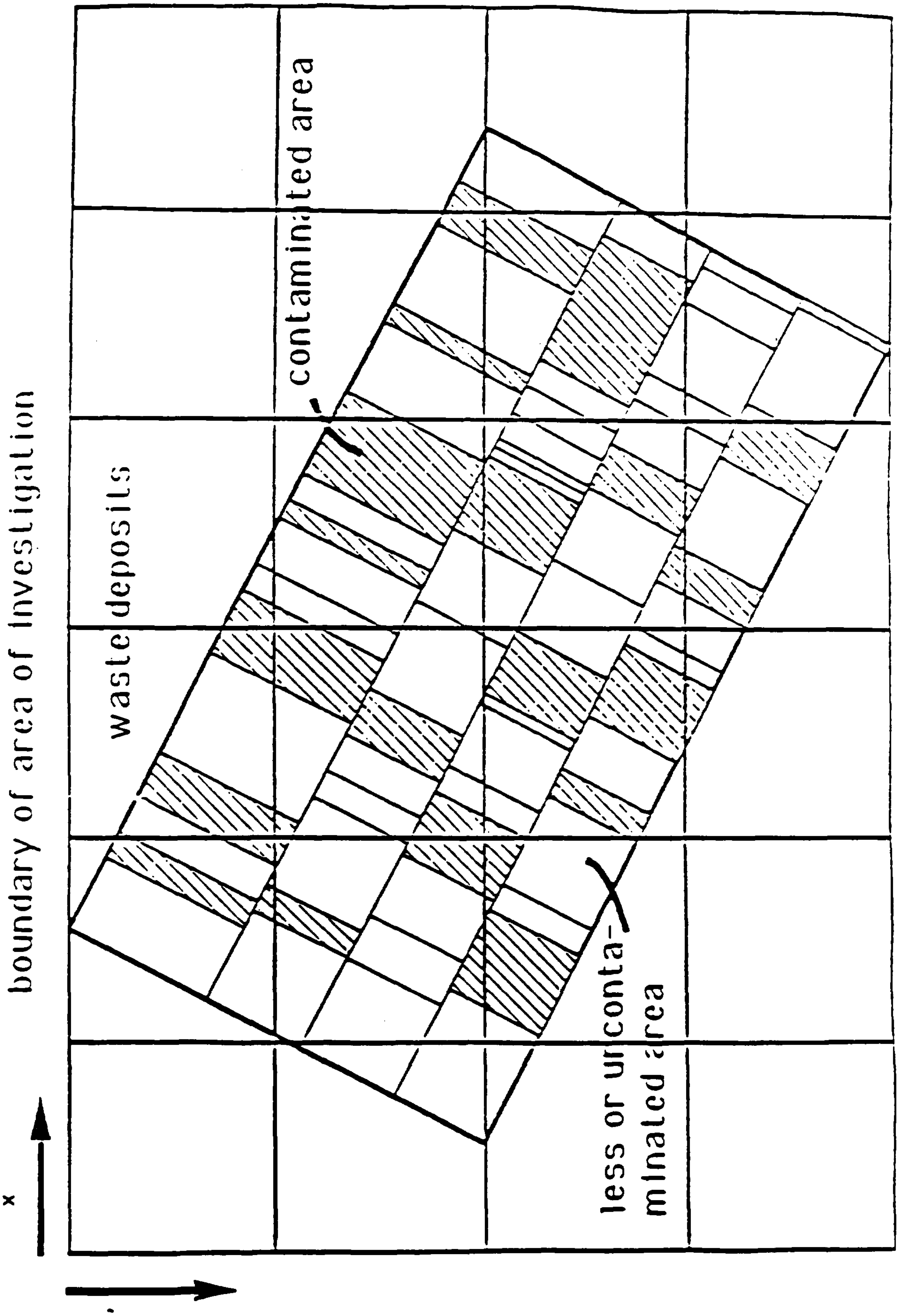


Figure 5: Example of Soil Contamination

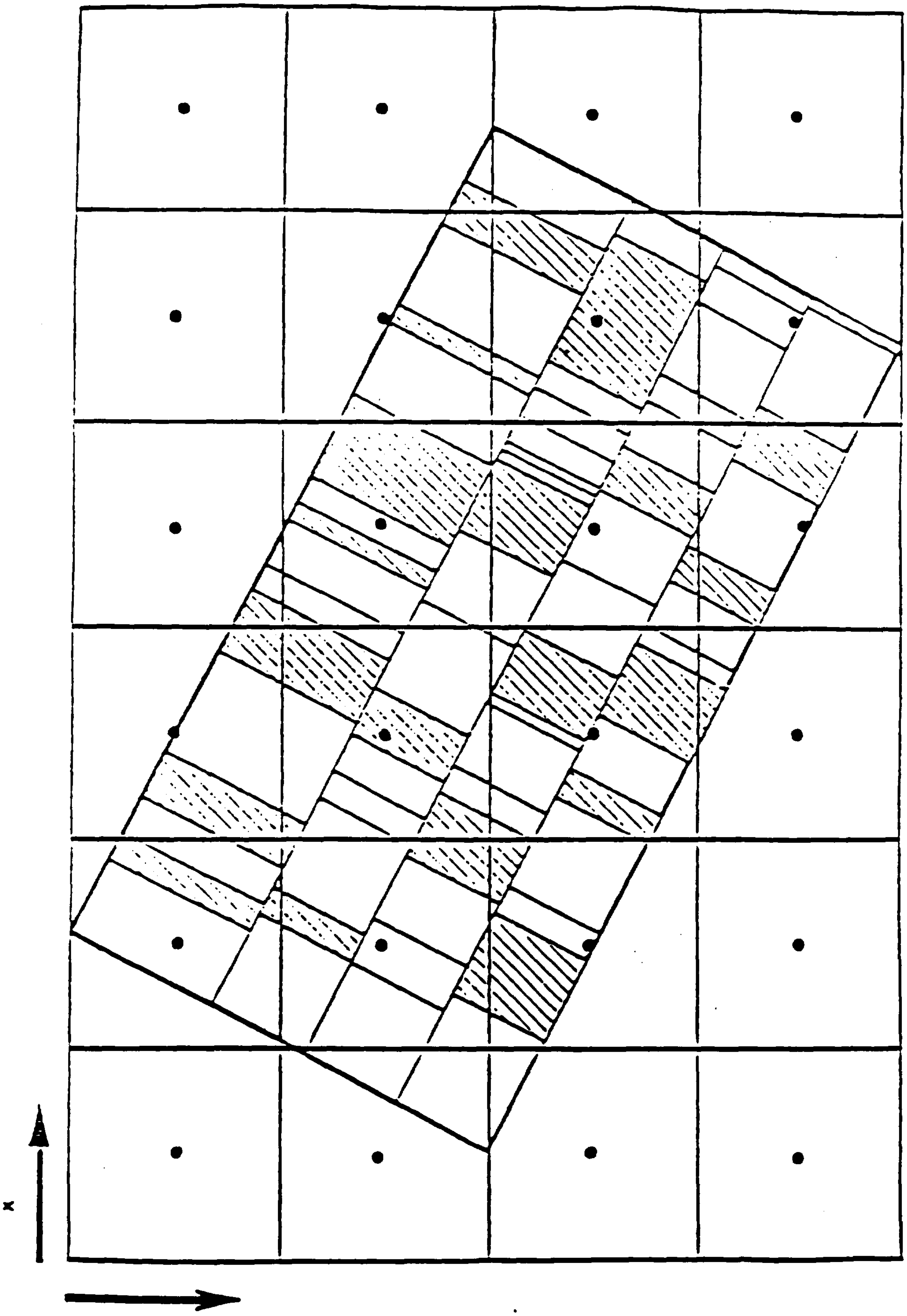


Figure 6: Regular Distribution of Sampling Points on a Regular Grid

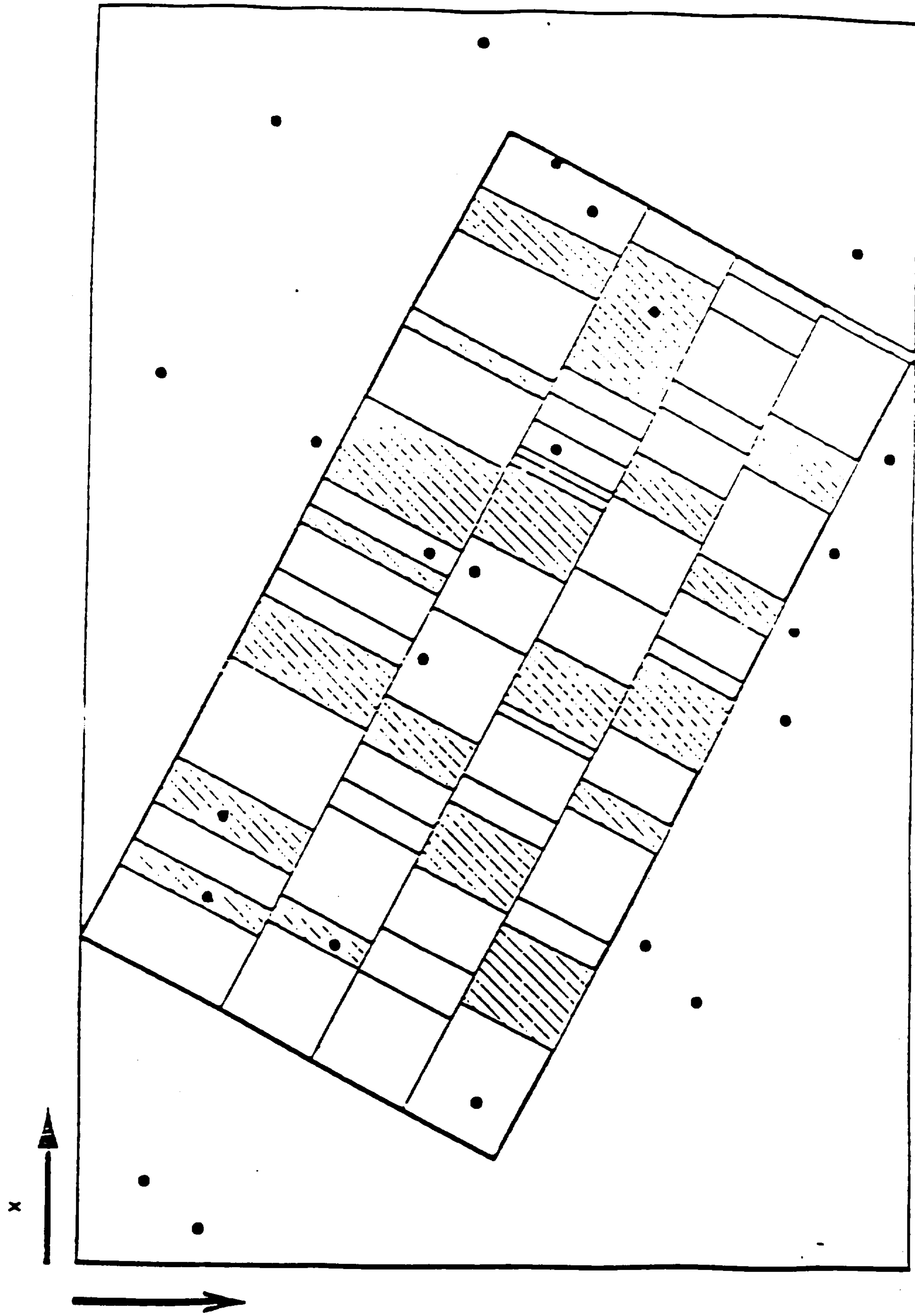


Figure 7: Random Sampling Without Grid

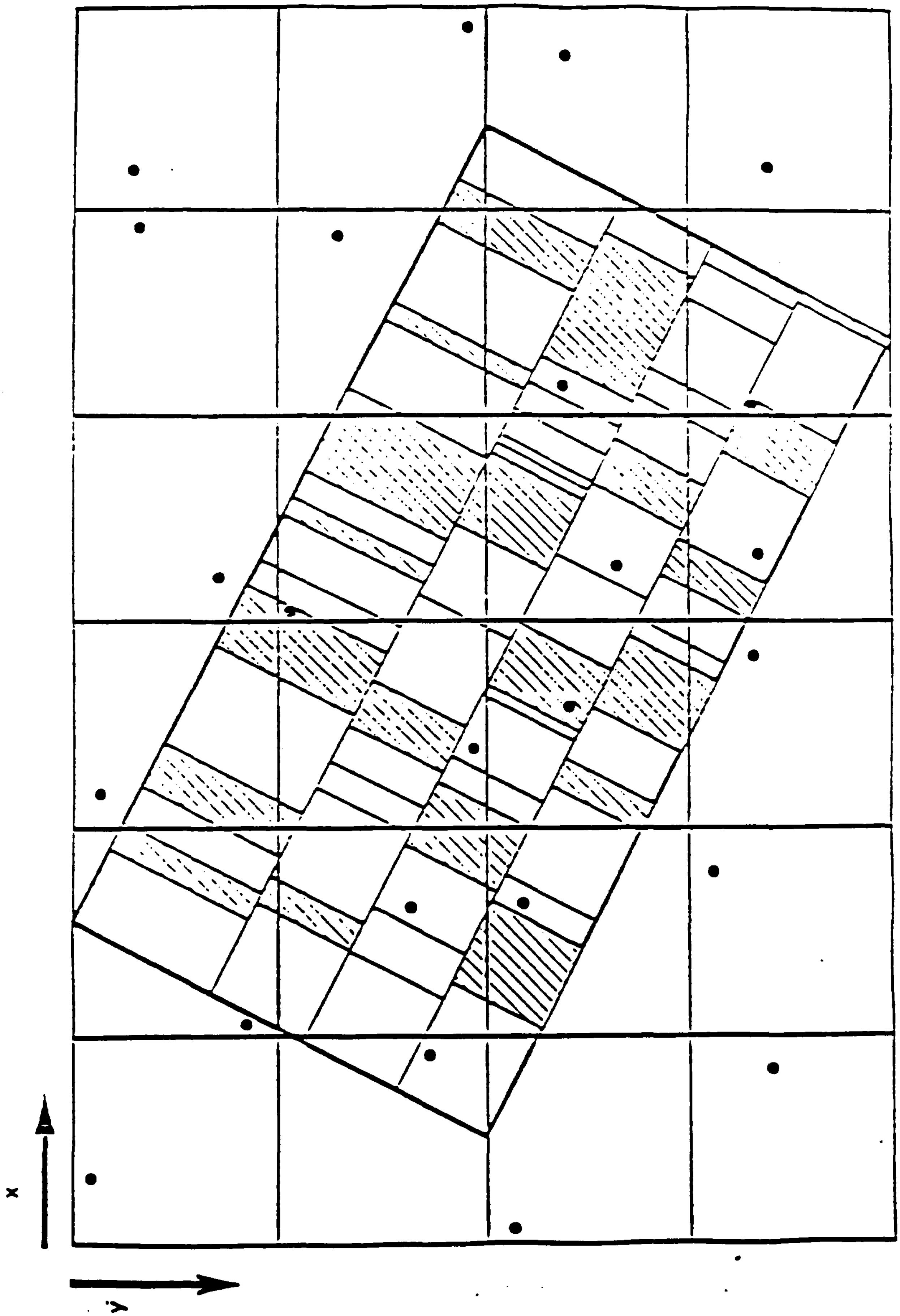


Figure 8: Stratified Random Sampling on a Regular Grid

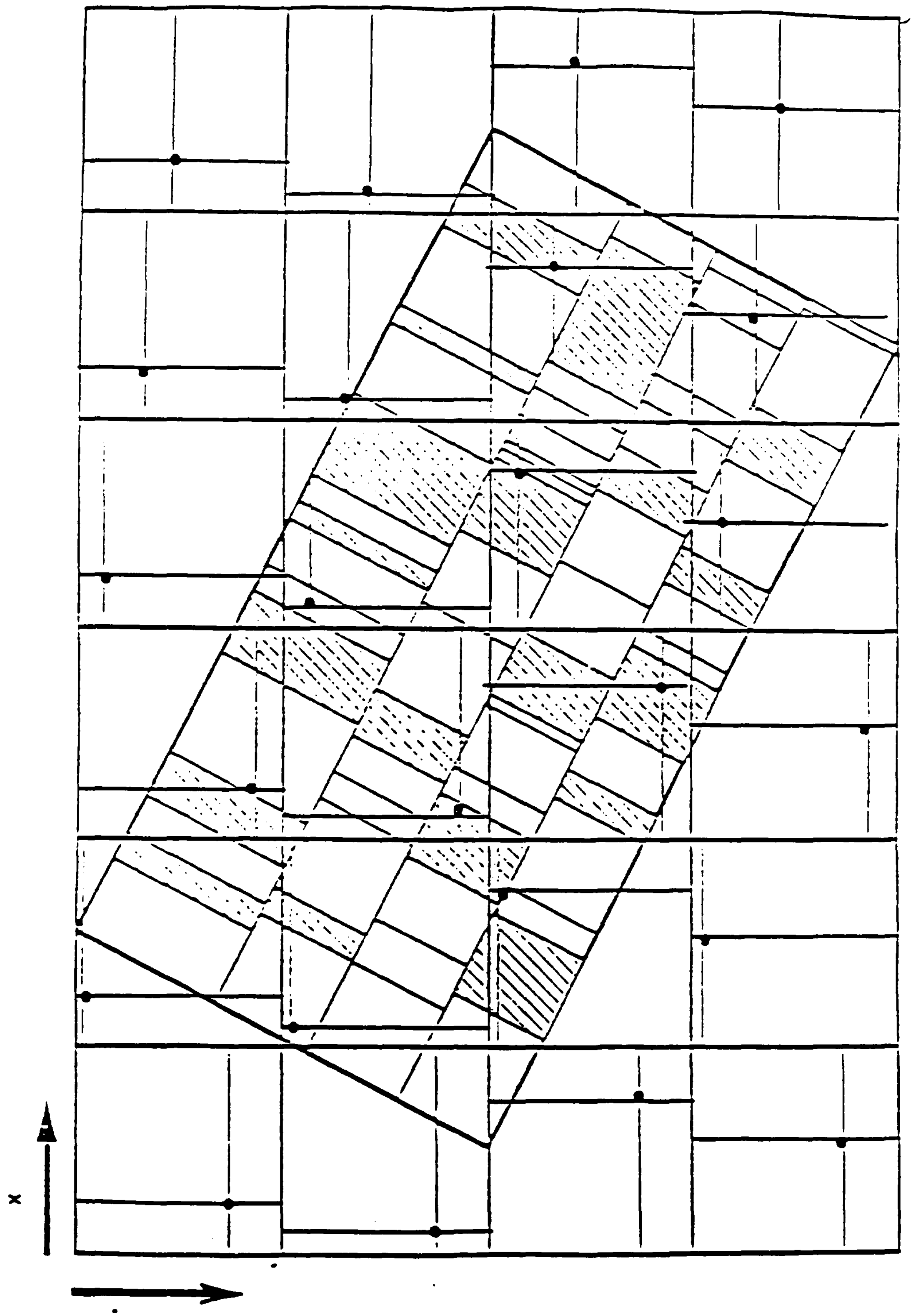


Figure 9: Unaligned Random Sampling on a Regular Grid

(4) All sampling points are now located on the grid:

For all sampling points in the columns, the y-coordinates of cells 2,3,4,5 and 6 are valid and for all sampling points in the lines the x-coordinates of cells 7,13 and 19 and valid.

In general, the spacing of each set of grid lines has to be fitted to the dimensions of the site and to the problem.

f. 'W' or 'X' Patterns

These are simple patterns in which the individual sampling points are located on linear traverses of the site, laid out in the form of an imaginary letter 'W' or 'X' drawn across the site. They do not depend on prior knowledge of the distribution of contamination and are therefore appropriate for sites having a heterogenous distribution. Because relatively few sampling points are used and the linear traverse do not cover all parts of a site, these patterns will not define the degree and extent of contamination adequately on contaminated sites. Their principal use has been in the sampling of agricultural land and geological formations as well as for such purposes as soil surveys and mapping. When utilized for these applications the samples collected from the individual sampling points are mixed prior to analysis, so that the date obtained represents average values concentration. This is a further disadvantage to their use in investigating contaminated sites (see figure 10).

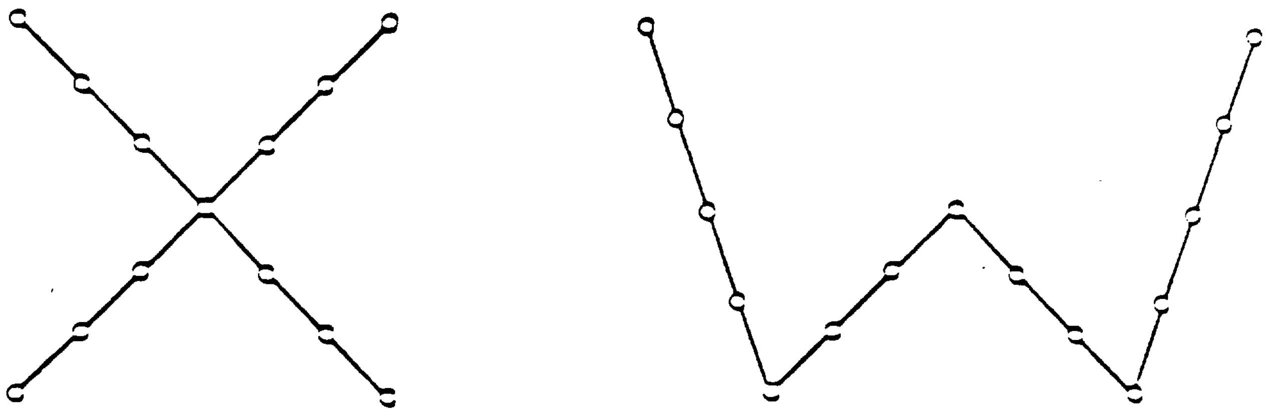
6. Depth of Sampling and Sample Quantity

Costs and the necessity to obtain homogenous material call for composite samples. It is necessary to take care that samples of potentially higher contaminated material are not mixed with less contaminated material (esp. coarse gravel, stony sands). Dilution in this manner may lead to concentrations below detection limits.

Only a portion of the samples from each auger should be used for composite samples. Part of the original sample thus remains available for special analysis later on.

The number of samples from a borehole depends on the kind of information asked for and on the degree of homogenity of the soil, especially within the soil profile. Different soil horizons should not be mixed. Comparability of analytical results is the main aim. These results should be interpretable in relation to the area, the soil, infiltration, etc.

The depth of sampling depends on the expected kind and distribution of the contaminant and the future development plans for the site.



X W

Figure 10: Non-Systematic Patterns

The sample quantity should provide enough material for homogenization and sub-sampling (see Table 15).

The sample quantity shall present as characteristic a cross section of the soil as possible and is to be chosen as a function of the maximum particle size contained therein, as indicated in the following table.

Table 15

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Estimated maximum particle size in soil sample in mm	Sample quantity in g not less than	
2	500	} 1000 minimum
5	500	
10	700	
20	2.000	
30	4.000	
40	7.000	
50	12.000	
60	18.000	

B. Equipment and Sampling

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1. General

The aim of soil sampling is to obtain material of representative composition to be used for physical, chemical and biological investigation.

From the technical point of view the main problem arises from the fact that different soil types require specific types of boring/digging. Based upon the results of preliminary investigations it should be known which soil profile and what groundwater levels are to be expected and which sampling tools are to be used.

2. Auger-Drilling

Augering by hand (e.g. groove borers, tube borers, rotating borers, sampling spoon for marshes, twist drills), has advantages in its simple application. It may also be used to carry out profile descriptions.

Applying these techniques has the disadvantage that only small amounts of (soil) material are obtained. Selection of types of augers should be adapted to the amount of material necessary. Care should be taken that the sample is representative for location and that cross contamination by the tool itself is avoided.

Advantages are:

- low costs
- possibility to take additional samples around a once fixed sampling point in a very short time to obtain a representative sample (clustering).

Stony soils or very thin soil layers cause difficulties in obtaining the necessary amounts of material. In cases like these samples must be taken from greater areas of equal soil horizon types.

3. Other Sampling Techniques

Other sampling techniques include percussion boring, pulse boring (water hammer), hydraulic bit boring, i.e. techniques used to teach a certain depth. Sampling has to be done by special methods. These techniques are more expensive and therefore need specially trained personnel or specialized operators.

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Disadvantages are:

- sampling requires a specialist on the site
- risk of contamination due to the use of tools, machines, drilling fluids, etc.

4. Diggings (trial pits)

Trial pits provide reliable information on stratification and types and character of soil, and state likewise the presence of any water body. They also make collection of soil samples easy and provide a direct means of testing the soil in the pit walls and at the bottom. However, the excavation of deeper pits is generally more expensive than hand borings. Below groundwater level or in cases of high flow groundwater ingress, pit will be of lesser value.

5. Special Equipment for Taking Undisturbed Samples for physical geological and biological purposes

C. Sampling

1. Documentation of Sampling Points

A sample should have a reference number which is composed of the x- and y- coordinates of the sample location and the depth of the sample location and a log should be attached.

Every sample should be entered into blank form including the date of sampling, depth of sampling, color (at native moisture), soil group (variety, form and a rough description after preliminary survey) land utilization, odor. The color may be compared to standard color codes.

2. Transport and Preservation of Samples

Sampling and storage should be done in accordance with the investigating laboratory.

If the survey parameters are not known definitely at the time of sampling, the use of glass bottles with wide mouth and standard ground joint for storage and transportation is recommended. If parameters are known, the use of other suitable containers is possible. Each container must be marked with the particular sample number.

During transportation it might happen that some kinds of soil, especially those which are non-cohesive, very dry or which contain higher amounts of stony material, are separated into single particle sizes. Before using these samples for analysis it is important to homogenize them again, (e.g. application of a mechanical sample splitter, but proceed with caution if parts of the apparaturs are made of chromium-nickel alloys or galvanized strip).

Samples should be stored cool and dark, if necessary.

D. Preparation for Analysis

Preparation for analysis is part of the analytical procedures and therefore dealt with in standards on soil analysis.

E. References

DIN 4021	Part 1	Subsoil; exploration by diggings (trial pits) and borings as well as sampling; indications in the soil
DIN 4022	Part 3	Subsoil and ground water; Designation and description of soil types and rock; Borehole log for boring in soil (loose rock) by continuous extraction of cores
DIN 4023		Borehole logging; graphical representation of the results
DIN 4047	Part 3	Water engineering for agricultural lands, terms; pedological basis
DIN 4220	Part 1	Soil evaluation for site description; survey and signification
DIN 18 121	Part 1	Subsoil; testing procedure and testing equipment, water content, determination by drying in oven
DIN 18 123		Subsoil; testing of soil samples, determination of the particle size distribution
DIN 18 915	Part 1	Landscaping; soil working for technical vegetation purposes, evaluation and grouping of soils
DIN 19 671	Part 1	Soil drillings apparatus for drawing soil samples in agricultural engineering; groove borers, tube borers
DIN 19 671	Part 2	Soil drilling apparatus for drawing soil samples in agricultural engineering; rod, rotating borers, sampling space, sampling spoon for marshes, twist drills
DIN 19 672	Part 1	Apparatus for drawing soil samples in agricultural engineering; apparatus for soil sampling in undisturbed situations
DIN 19 672	Part 2	Apparatus for drawing soil samples in agricultural engineering; apparatus for the investigation and drawing of peat samples
DIN 19 680		Methods of research in agricultural hydraulics; ascertainment of soil profiles and observation of the groundwater

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DIN 19 681 Methods of research in agricultural hydraulics; taking soil samples

1 Bodenkataster Bayern, Merkblatt furdie Entnahma und Aufbereitung von Bodenproben zur Untersuchung von Schwermetallen in Boden- herausgegeben vom Bayerischen Geologischen Landesamt, Munchen 1985.

2 Seifert, D (1985): Bestimmung von Blei, Cadmium, Zink, Nickel, Thallium und Arsen in Boden und Siedlungsabfallen (Klarschlamm, Mullkompost): Kritische BEstandsaufnahme und Empfehlungen - Joseph-Konig-Institut, Landwirtschaftskammer Westfalen-Lippe, Einzelstudie zum FE-Vorhaben, 104 03 186, Dez. 1982.

3 Bodembescherming SSB - Voorlopige praktijkrichtlijnen - Herausg. Ministerie van V.R.O.M. Staatsuitgeverif, s'Gravehage, 1986.

4 Bodembescherming 56 - Aanpak van veldonderzoek bij genallen van lokale Bodemverontreiniging - Heraus.: Ministerie van V.R.O.M., Staatsiutgeverij, s'Gravenhage, 1986.

5 Bodenschutzkonzeption der Bundesregierung - Der Bundesminister des Inneren, Bonn 1985.

6 Zusammenstellung Bodenschutzender Rechtsvorschriften des Bundes -Umweltbundesamt Berlin, 1984.

SUPPLEMENT 2

SUPERFUND SOIL LEAD ABATEMENT DEMONSTRATION PROJECT PROTOCOL FOR SOIL SAMPLING AND ANALYSIS

SOIL SAMPLING

A. Site Description

1. General Site Description

For each location, a detailed drawing should be made that shows the boundary of the lot, the position of the main building and any other buildings such as storage sheds or garages, the position of the sidewalks, driveways, and other paved areas, the position of the play areas if obvious, and the position of the areas with exposed soil (grassy or bare) (See Figure 11). Show down spouts and general drainage patterns. Identify each soil subarea by letter or number. If a large soil area needs to be divided into smaller patches for sampling convenience, show how this division was made.

In addition to the diagram, briefly describe the location, including the following information:

Type of building construction
Condition of main building
Condition of lot (debris, standing water, vegetation cover)
Nature of adjacent property
Presence and type of fence
Animals on property
Apparent use of yard (toys, sandbox, children present)
Underground utilities

2. Subarea description

For each soil subarea identified on the general diagram, draw a full page diagram showing the approximate dimensions and position relative to the building foundation (see Figure 11). Indicate vegetation and bare soil areas, as well as obvious traffic patterns. Identify the category of landuse, such as roadside, property boundary, adjacent to foundation, play area. Select an appropriate sampling scheme and mark the sample locations on the diagram.

3. Sampling Schemes

The sample scheme selected for each subarea must adequately characterize the potential exposure of children to lead in the dust from this soil. It must identify the areas of high lead concentrations, and the general distribution pattern of lead concentrations at the soil surface. For abatement purposes, the depth to which lead has penetrated the soil profile must be determined. Consequently, selecting the most appropriate sampling scheme is the critical element in the site description. Several options are offered for the best judgement of the investigator.

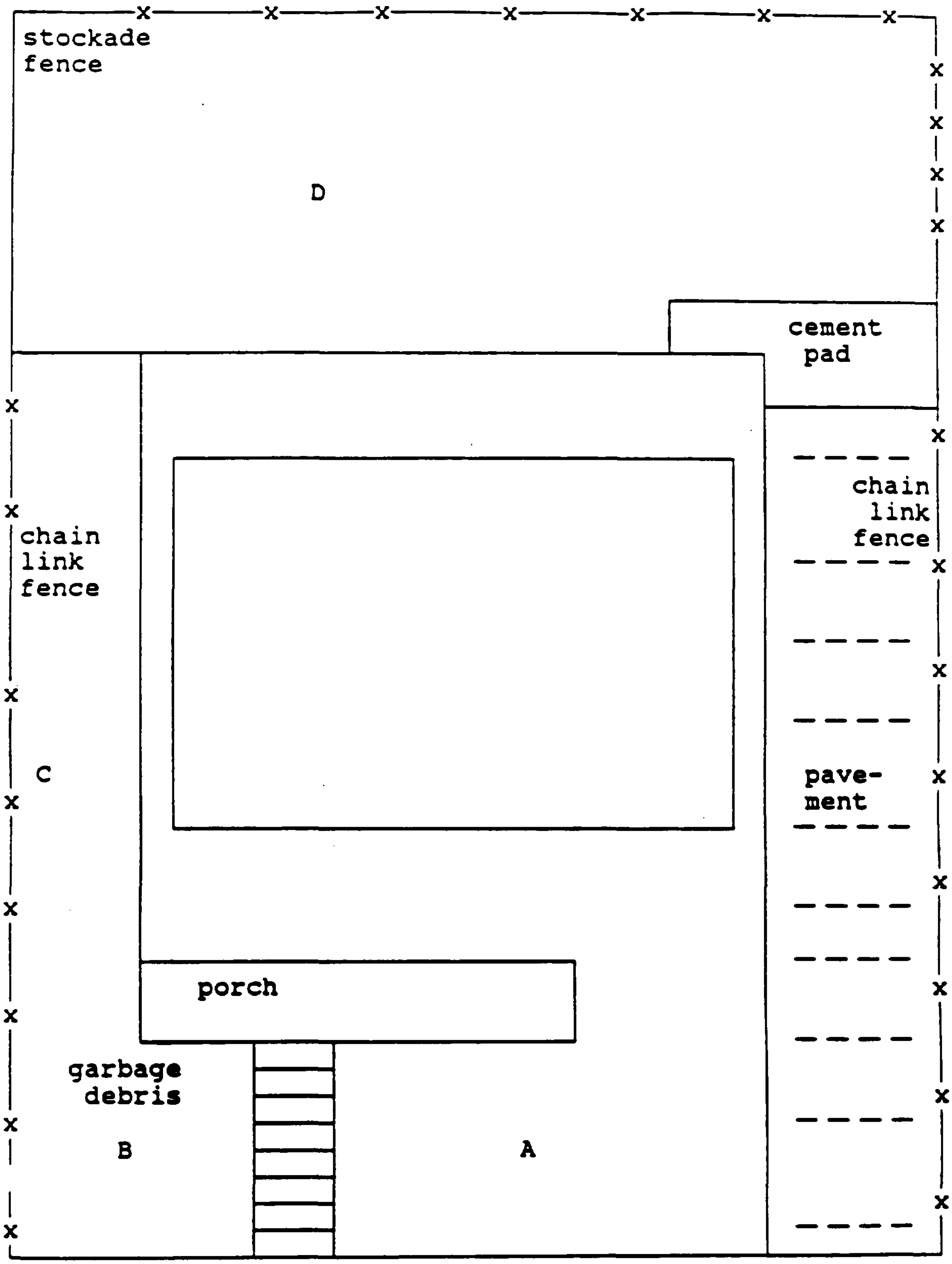

Figure 11. 37 Havlock Street
Site Sketch and Sample Diagrams

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a. Line Souce Pattern. This pattern can be used whenever the source of the lead is thought to be linear, such as along a building foundation, a fencerow, a street, or beside a garage. Draw a line parallel to the souce, such as the foundation of the main building, approximately 0.5 meters (20 inches) from the foundation. Repeat at the property boundary if the subplot is more than three meters wide (10 ft.), and add a third parallel line between the first two if the subarea exceeds five meters (16 ft.) in width. Divide each line into segments that do not exceed 7 meters (20 ft.) in length. Take on composite of 5-10 cores along each line segment. A subarea, for example, that is at the side of the main building and measures 12 x 7 meters would have three lines of two segments each. The lines would be parallel and approximately three meters apart. They would be 12 meters long and consist of two 6 meter segments each, making a total of six samples, each being a composite of at least five cores divided into a top 2 cm sample and a bottom 2 cm sample. (Figure 12, Diagram 1-A).

b. Targeted Pattern. This method is intended to be used in conjunction with the line source or grid patterns as a means of sampling obvious areas that would be missed by the regular patterns. In using the targeted pattern, the investigator should select those locations within the subarea that are likely to reflect potential exposure to lead in soil dust. These may be play areas, paths, drainage collection areas, or areas that are likely to contribute dust to other surfaces that children use. Determine the number of samples to be taken by identifying distinctive landuse characteristics (path, swingset, sandbox), and take a composite of 5-10 cores for each sample. (Figure 12, Diagram 1-B).

c. Small Area Pattern. When the subarea is less than two meters in each dimension, or when the accessible area of a larger plot is less than four square meters, a single composited sample may be taken if it appears that such a sample would adequately represent the subarea. (Figure 12, Diagram 1-C).

d. Grid Pattern. Establish a rectangular grid of intersecting lines 2-10 meters apart, and sample each rectangular area. For larger areas, randomly select the rectangles to the sampled. In each rectangular area, mark three lines parallel to the longest axis, and composite 5-10 cores along each line. Since the rectangle sould not exceed four meters, there is no need to divide the line into segments. Therefore, each rectangle should have six samples of 5-10 composites each. Use this pattern when the subarea is generally uniform and there is no reason to suspect large variations in lead concentrations. (Figure 13, Diagram 1-A).

e. Visual Location. When the sample sites have been located on the subarea diagram and the sample collection is ready

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Example of Neighborhood Sampling Pattern

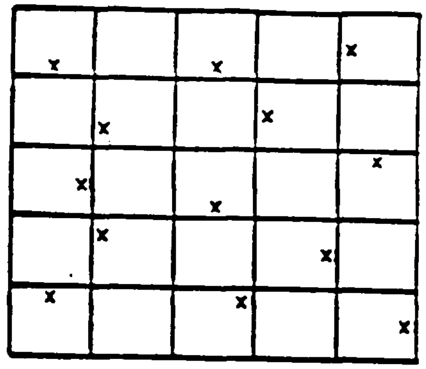
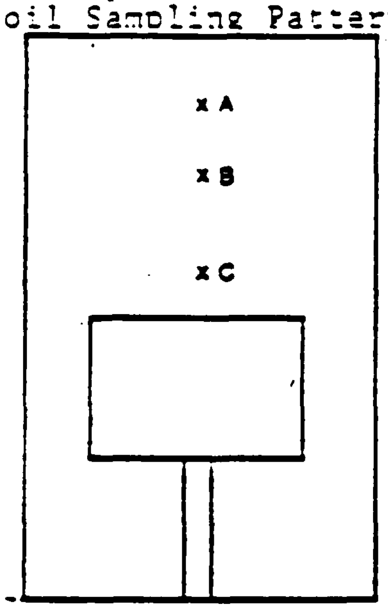


Diagram 1-A

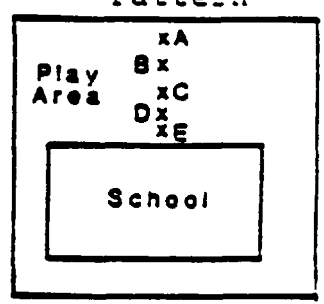
Example of Yard Soil Sampling Pattern



Composite of 2" Plug 6" Depth A, B, & C Yielding a Single Value for this Home (Litter Removed)

Diagram 1-C

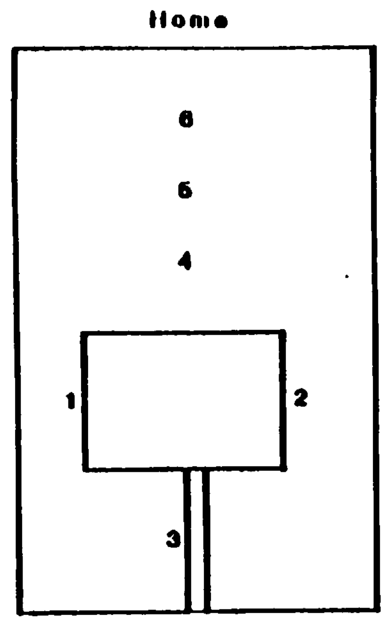
Example of School Playground Sampling Pattern



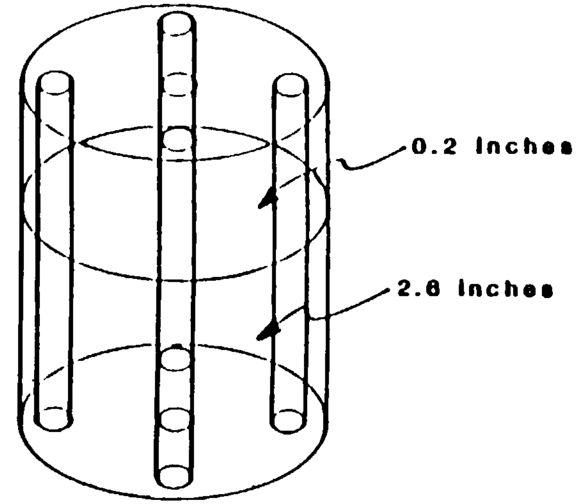
Composite of 2" Plug 6" Depth A to E Yielding a Single Value

Diagram 1-B

Figure 12 Preliminary Soil Sampling



12-18 Composite Samples
Analysis will be Performed
on Each Home
Diagram 1-B



Remove Litter
Composite 5 Plugs 0-2" Deep
Composite 5 Plugs 2-6" Deep
Diagram 1-C

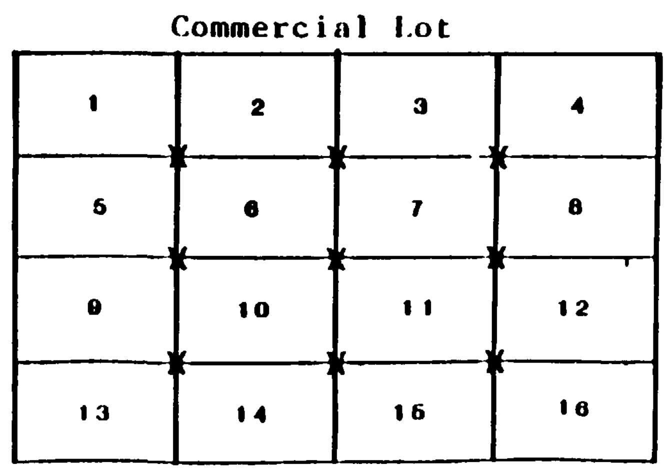


Diagram 1-A

Figure 13. Detailed Soil Sampling

to proceed, locate each sample with a flag and visually confirm an even and representative distribution of sample location. (Figure 13, Diagram 1-B).

B. Sample Collection

The flags or other markers represent the center of the sample location for the targeted and small area patterns. For the line source and grid patterns, the flags indicate the sampling lines. Take at least five but not more than ten cores randomly selected from within the sampling area of the targeted and small area sampling patterns, and uniformly spaced along the sampling lines of the line source and grid patterns. The cores make a composite identified as a single sample. A sample record sheet is used to record information about the composite. The corer should be clean and free of lead contamination. Vegetation and debris can be removed at the point of insertion, but do not remove any soil or decayed litter. The corer should be driven into the ground to a depth of at least 10 cm, 15 cm if possible. If the 10 cm depth cannot be reached, the corer should be extracted and cleaned, and another attempt made nearby. If the second attempt does not permit a 10 cm core, the sample should be taken as deep as possible, and the maximum depth of penetration noted on the sample record sheet. Every effort should be made to take all cores of a composited sample at the same depth.

The cores of each plot should be examined for debris, artifacts, and any other evidence of recent soil disturbance. These should be noted on the subarea description sheet, as should a brief description of the soil color and soil type.

For each sample location, the top 2 cm segment of each of the cores are composited into one sample, and the bottom 2 cm segment combined into a second. For the surface segment, debris and leafy vegetation should not be included with the sample. However, no soil or decomposed litter should be removed, as this is the most critical part of the soil sample and is likely to be the highest in lead concentration.

The soil core segments should be composited in sealable polyethylene containers suitable for prevention of contamination and loss of the sample. The sample identification number should be placed on the container and the sample record sheet. After each sample composite, the corer should be cleaned by reinsertion in the next sampling area. Store the composited soil sample at ambient temperature until returned to the lab.

A field blank* should be taken for each sample crew day. This is normally done by taking a sample container with clean quartz sand into the field, opening it to expose the container for a period of time representing normal sample procedures, then returning the container to the lab in the same manner as other soil samples. The purpose of the field blank is to detect

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accidental or incidental contamination during the sampling process. Figure 14 illustrates a national sampling strategy and classification of samples.

*Field blank was deleted at Boston coordination meeting.

C. Sample Handling And Storage

The sample containers should be sealed to prevent loss or contamination of the sample. Shipping containers should also be airtight. Storage should be in a cool, dry location.

D. Record-Keeping And Sample Custody

Soil sample records for each location consist of a location diagram and description, a plot diagram for each distinct soil plot, and sample record sheet for each sample in a plot. The sample record sheets should also contain space for chain-of-custody documentation.

Samples should be sequentially numbered within each subarea. Each location diagram, subarea description, and sample record sheet should bear all sample numbers and the signature of the person responsible for verifying the quality of the information collected. This signature certifies that there has been no misuse of the sample protocol, no mistake in recording the information, and that the information is sufficient to clearly identify these samples for comparison with other types of samples taken at the same location, such as street dust, house dust, house paint, blood, and hand dust. These documents also establish the chain of custody required for the Quality Assurance Plan.

When the sample is delivered to the laboratory, custody is relinquished by the field investigator and received by the lab supervisor by signatures on the sample record form.

SAMPLE ANALYSIS

A. Method Of Analysis

Three methods of analysis have been considered. They are Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Emission Spectroscopy (ICP), and X-Ray Fluorescence (XRF). The XRF method is the approved method for routine analyses, whereas the AAS method should be used for standardization.

1. Sample Definition. The representative urban soil sample is defined as the soil from 0-2 cm depth that passes a 250 cm stainless steel seive. This fraction is comprised of small particles, and the concentration of lead believed to be closely related to that of particles on the hands of children. The

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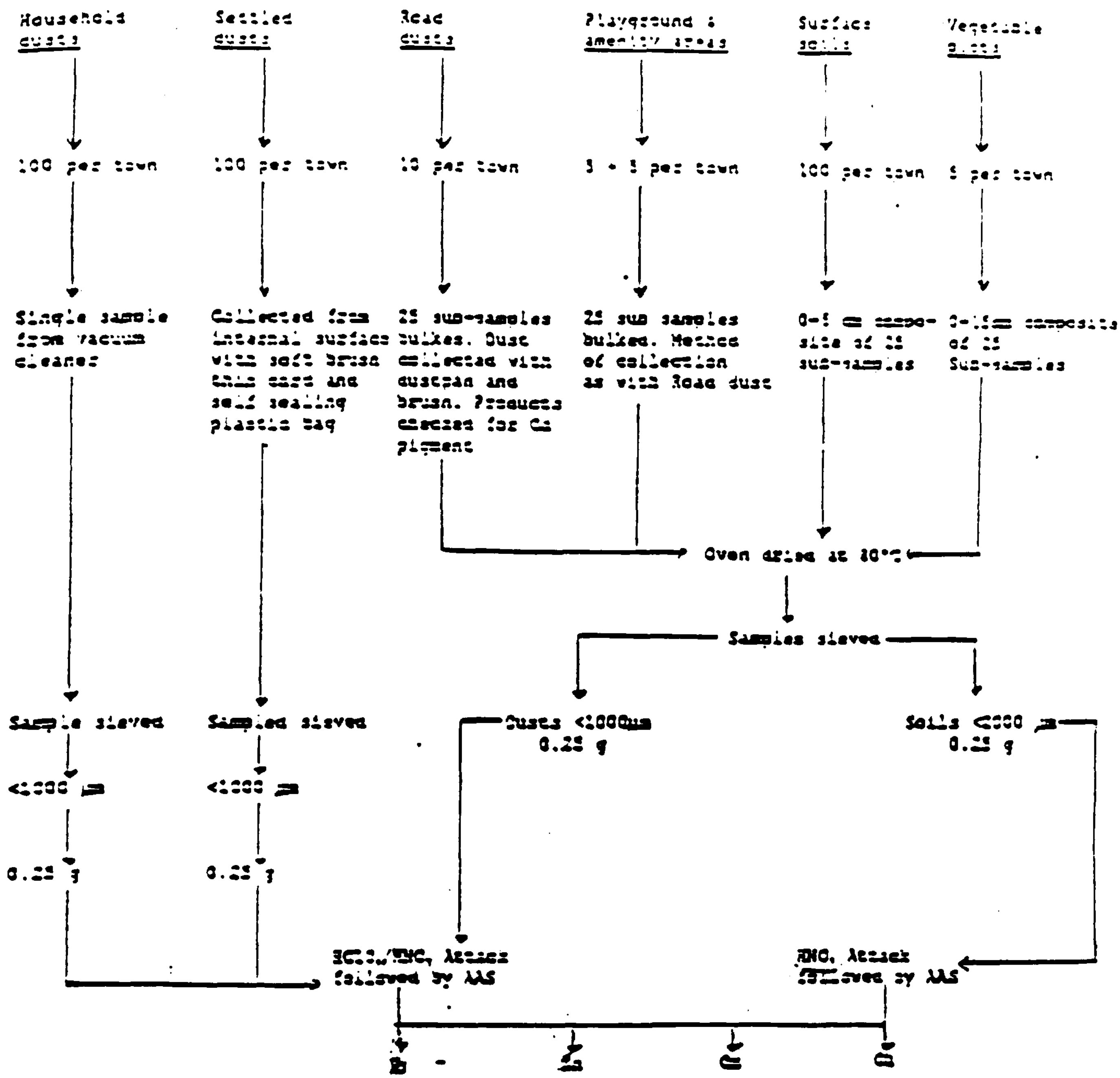

Nationwide Reconnaissance Survey of Metals in Dusts and Soils
Sampling Strategy and Classification of Samples

Figure 14. Nationwide Reconnaissance Survey

If here ... diagram ... Cannot get a more legible copy?

fraction is also homogeneous enough to allow reliable analysis by X-Ray fluorencence.

2. Sample Preparation. Sample preparation requires that the sample be air dried and separated by particle size before being digested by wet chemistry. Drying is done at room temperature overnight or until the sample can be easily disaggregated by hand or with a rolling pin. The full sample should be brought to complete disaggregation by passing through a 2 cm sieve, using the fingers or a stainless steel tool to crush the larger soil particles. Material larger than 2 cm should be discarded. Soil should not be milled to a fine powder with a morter and pestle or any other grinding device.

The fraction that passes the 2 cm sieve is now called the total soil fraction. A portion of this sample is retained for possible reference analysis, but the larger fraction is passed through a #60 mesh sieve (250 μm), giving a fine soil fraction identified as the "Urban Soil Sample". The portion that does not pass the #60 mesh sieve should be discarded, as only the total soil fraction (<2 mm) and the fine soil fraction will be analyzed.

About 5-10% of the retained total soil samples should be analyzed. An aliquot is ground so that it all passes a #60 mesh (250 μm) sieve, mixed well and analyzed. Grinding is necessary to provide low/appropriate variance in XRF analysis.

During the processing of the sample, it should be remembered that small soil particles may individually be as high as 50,000 μg Pb/g, and paint fragments as high as 300,000 μg/g. Care should be taken to clean equipment between samples. The sieves may be cleaned by tapping on a hard surface to remove residual particles, or any other dry method. Wet washing is not recommended as this will interfere with the size calibration.

Care should also be taken to thoroughly homogenize the separated sample before removing the aliquot for analysis. Shaking will cause separation. Tumbling or stirring is recommended.

B. Atomic Absorption Spectroscopy (To be used for primary standards)

1. Wet Digestion. The extraction procedure used for solubilizing soil lead is critical to the interpretation of the results of the Superfund Soil Lead Abatement Demonstration Projects. Even in the absence of analytical errors, the data may not represent the same lead concentrations from sample to sample unless the correct extraction procedure is used. The method selected here does not represent the total extraction of lead, but the breakdown of the organic material and the leaching of lead from the inorganic soil fraction. The methods measure total

non-matrix soil lead, because no other extractable fraction has been experimentally shown to measure bioavailable, or non-HF extractable, soil lead. Hot HNO_3 has been repeatedly shown to extract total non-matrix soil lead, or at least >95% of soil lead, compared to a total soil dissolution method (HF). The 1.0 N HNO_3 chold shake method has been shown to extract as much lead as the hot HNO_3 extract, except for unpolluted soils where a higher fraction of the total soil lead is within the matrix of soil particles.

The sample should be oven dried at 105°C for 24 hours or until a constant weight is achieved. The aliquot should be placed in a 150 ml beaker and covered with a watch glass. Class A borosilicate glassware and stainless steel tools should be used throughout the sample processing. Low density conventional polyethylene containers may be used to store the solution prior to analysis.

An aliquot of 1 g soil is normally considered representative of the whole sample if the soil is well mixed. Prior to removing the aliquot, the sample should be stirred with a spatula or rod. Shaking the container can cause the sample to separate by particle size.

2. Hot HNO_3 Extraction. Add 50 ml 7N HNO_3, cover and digest gently at 95°C for 2 hours, stirring occasionally. If excessive foaming occurs, remove from the heat periodically until foaming subsides. Maintain at least 25 ml in the beaker by adding 7N HNO_3 as necessary.

Cool and dilute with 10 ml 1N HNO_3. Filter through Whatman No. 42 filter paper into a volumetric flask. Rinse filter and labware with 1N HNO_3, and dilute to volume.

3. Cold HNO_3 Extraction. Weigh the 1 g aliquot into a 4 oz. urinalysis cup. Add 50 ml 1.0 N HNO_3 to each cup. Screw the lid on tightly and place on a reciprocal shaker. Adjust the speed of the shaker to maintain a suspension of the soil particles. Shake for one hour, then filter through a Whatman 111-V filter. Rinse with 1.0 N HNO_3. Dilute to standard volume.

4. Analysis. Analysis by flame AAS should be at 283.3 nm, with background correction. Working standards should be prepared fresh daily, in the range of 2-50 μg/g, in a 1.0 N HNO_3 matrix.

5. XRF Analysis.

Approximately 2 g of loose soil sample are poured into sample cups (Somar Labs, Inc., Cat No. 340), fitted with windows of 1/4 mil thick X-ray polypropylene film (Chemplex Industries, Inc., Cat NO. 425). The sample cup should be at least half full. The sample cup is sealed with a sheet of microporous film (Spex

Industries, Inc., Cat No. 352A) held in place by the snap-on sample cup cap. The exact weight of the sample is not important, but should be in the range of 2-6 g.

The instrument configuration for the Kevex Delta Analyst Energy Dispersive X-ray Spectrometer is:

1) Kevex Analyst 770 Excitation/Detection Subsystem:

a) X-ray tube: Kevex high output shodium anode
b) Power supply: Kevex 60 kV, 3.3 mA
c) Detector/cryostat: Kevex Quantum - UTW lithium, drifted silicon. 165 eV FWHM resolution at 5.9 KeV.

2) Kevex Delta Analyzer:

a) Computer mainframe: Digital Equipment Corp., PDP 11/73
b) Computer software: Kevex XRF Toolbox II, Version 4.14
c) Disk drives: Iomega Bernoulli box, dual drives, 10 MB
d) Pulse processor: Kevex 4460
e) Energy to digital converter: Kevex 5230

3) Operating conditions:

a) Excitation mode: Mo secondary target with 4 mil thick Mo filter
b) Excitation conditions: 30 kV, 1.60 mA
c) Acquisition time: 300 livetime seconds
d) Shaping time constant: 7.5 microseconds
e) Sample chamber atmosphere: air
f) Detector collimator: Ta

4) Analytical conditions:

a) Escape peaks, but not background should be removed from all spectra
b) The intensity ratio, defined as the integral of counts in the Pb (LA) window divided by the integral of the counts in the Mo (KA) Compton scatter window, should be determined for each spectrum
c) The intensity ratios for the standards should be used to determine a linear least squares calibration curve
The acquisition time (3c) may be reduced at the discretion of the lab supervisor.

6. <u>QA/QC</u>.

By blind insertion into the sample stream (where possible), the QA/QC officer will provide the following blanks at the indicated frequency. At the discretion of the project director, the field team will collect one blank per day by carrying a sample of clean quartz sand into the field in a normal sample container. The sample container will be opened and exposed during the collection of one sample, then closed and returned to the lab. The field blank can be split into two aliquots. One aliquot, the field blank, can be analyzed directly with no further treatment. The second aliquot (the sample blank) can be analyzed after it has passed through the sample stream (except sieving). The field blank represents contamination added in the field, the sample blank represents contamination added in the field and during storage and sample preparaion.

A project standard soil sample will be prepared and distributed at the beginning of the study. This will be used as a lab control. For XRF analysis, there is no need for a reagent blank.

Field blank*	1/field sampling day
Sample blank	1/field sampling day
Lab control	1/20 samples
Reagent blank	3/reagent batch

Additionally, split sample (duplicate) analyses and spiked samples** will be determined as follows:

Split soil	1/20 samples
Spiked soil	1/20 samples

The spiked soil samples will be prepared by mixing dried and sieved soil of known concentration with the sample. Spiked soil samples may be used at the discretion of the project director. Additional split soil samples will be sent to a designated QA/QC laboratory for analysis using the hot HNO_3 method, one for each 40 samples.

An interlaboratory comparison, similar to the soil pilot study, will be conducted during each six month period, with 10-20 samples from each laboratory, including the QA/QC lab. These samples will be dried, but not sieved.

*Field blank was deleted at Boston coordination meeting.
**At Boston coordination meeting the spiked soil sample was deleted.

no field blanks
no spiked samples

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SUPPLEMENT 3

DATA HANDLING AND PATTERN RECOGNITION FOR LEAD CONTAMINATED SOILS

A. INTRODUCTION

In the experimental sciences hypotheses are tested by devising procedures in which the effects of any disturbing factors are closely controlled or minimised. But in the field sciences hypotheses are tested by sampling, analysis and data evaluation. The analytical data are essentially "noisy". Some indirect control is possible since a carefully prepared sampling protocol will ensure that samples are "representative" and collected from similar environments and confined to a single species. Known or suspected influences can be recorded, quantified and their effects compensated for later on. But even if sampling and the subsequent analyses are done correctly the researcher is still faced with the problem of making sense out of a mass of variable data.

There are many laboratory manuals which provide guidance on the choice of analytical techniques and quality assurance controls. In contrast with the ready availability of laboratory manuals, advice on data interpretation is scattered in the literature. There are, of course, some admirable texts covering elementary statistics but it is the experience of most practitioners that their usefulness is limited when dealing with "real" data. The objective of this supplement is to describe a systematic approach to the interpretation of one kind of field data, namely lead concentrations in soil samples derived from systematic or random surveys. A knowledge of standard statistical tests is assumed and further information on these may be derived from Cole and King (1968), Davis ~~(1973), Krumbein~~ and Graybill (1965),Mead and Curnow (1983), Parker (1973) and Till (1974).

not in ref's

B. THE NATURE OF SOIL LEAD DATA

The simplest descriptive statistic is the mean, the sum of the measurements divided by the number of measurements. Besides calculating the mean, computer packages usually provide the standard deviation, the spread of the values around the mean. It is also helpful to establish the minimum and maximum values. But data assessment should not stop at this point since these parameters do not fully evaluate the data. It is important that the median value be calculated. This is the middle value when metal concentrations are arranged in order of increasing concentration.

Table 16 illustrates soil lead concentrations from a typical survey (Davies and Ginnever, unpublished data). The arithmetic data are characterised by a feature which is common in this kind of data, namely that the mean is greater or very much greater

Table 16

A summarisation of soil lead concentrations derived from 174 soil samples collected in north Somerset

	mg Pb/kg soil	
ParameterB	Arithmetic,	Transformed
Mean,	1838	66
Median	52X	52
Minimumn	8n	8
Maximumn	10223	10223
St. Devn.B	798B	3 h"X2

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than the median. The most common inference drawn from the value of the mean is typicality, the average value. But the median is also a measure of central tendency. It is the value of the middle sample when all sample values have been arranged in rank order from lowest to highest. The two statistics are seen to differ in Table 16, the mean being 3.5 times greater than the median. The distribution is positively skewed and in this instance the median far better represents central tendency than does the mean.

Many statistical packages will also provide the skewness or third moment statistic. A positive value indicates a clustering of samples to the left of the mean.

The most commonly used statistical techniques (analysis of variance, regression analysis or correlation analysis) are so-called 'parametric' tests. They require the test populations to be normally distributed, i.e., they should not be skewed. Populations can be normalised by transforming the data and a common transformation is to convert each value to its logarithm (the common log10 or the natural loge). Table 16 shows the result of a log10-transformation. Recalculation and anti-logging yields the geometric mean (66 mg/kg) which is only 1.3 times the median (52 mg Pb/kg). The reduction in spread is reflected in the geometric deviation (3.0) compared with the standard deviation (798). As a general rule, all soil lead data should be log-transformed before statistical analysis.

The way in which the range is quoted needs careful consideration. Of course the observed range should be published as in Table 16. But only the very occasional sample in the study area approaches the observed maximum (1.0% Pb, rounded). A different measure of range must be used if typicality is to be inferred. Any introductory text on statistics will explain the normal distribution curve. A property of this curve is that the proportion of the area underneath it is described by the mean +/- some multiple of the standard deviation. The mean +/- 2s accounts for 95.5% of the area and the mean =/- 1.96s accounts for 95% of the area. Similarly, mean +/-3s accounts for 99.7% of the area and mean +/- 2.58s accounts for 99% of the area. From this it is useful to quote the 95% probability range (mean +/-1.96s) using the log-transformed data. This was done for the data summarised in Table 16 and indicated that for the Mendip Hills of north Somerset most soil lead concentrations lie between 8 and 577 mg Pb/kg.

The approach outlined above is not, of course, the only way of summarising voluminous data. But the suggested statistics are easily calculated using a microcomputer. Appropriate programs can be written in BASIC or are available as commercial packages.

What did they do here?
[mean log ± 1.96 s(logs)]?
exp

$\log_{10} 66 = \bar{X}(\log_{10}) = 1.8195$

$\log_{10} 3 = s(\log_{10}) = .4772$

$1.8195 + (1.96)(.4772) \approx$

$\exp(2.75) \approx 563 \approx$

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C. IDENTIFICATION OF CONTAMINATED SOILS

There is no simple, unequivocal way of recognising when a soil has been contaminated or polluted by lead since it occurs naturally in all soils, albeit at very low concentrations. The problem of recognising whether contamination has taken place becomes one of deciding whether the measured concentration is within the range of what could occur naturally for that soil or whether the measured concentration is anomalous.

Quantitative approaches to the description and evaluation of lead and other trace element data for soils are still in their infancy and it is not clear what is the best model to describe the variability of soil metal concentrations. Ahrens (1954, 1966) has proposed that the distribution of elements ~~in igneous~~ rocks approximates to a log-normal distribution. This model does not necessarily apply to soils but the available evidence suggests it may. Its applicability underlies the interpretation of geochemical data in mineral exploration.

Rose et al. (1979) discuss the concept of threshold, the upper limit of normal background fluctuations. Values above background are considered anomalous. This approach is directly applicable to contamination studies since a contaminated soil is an anomalous soil. The simplest way of identifying threshold concentrations is by collecting samples from apparently uncontaminated areas (e.g., those remote from urban or industrial influences). After analysis the geometric means and deviations are calculated. The threshold is then the value lying two or more standard deviations from the mean, depending on the probability level required. An anomalous value is one which lies above the threshold. Where more than one sample is apparently anomalous then the differences between the two groups (control and anomalous) can be assessed by standard statistical tests such as the familiar t-test.

Very often it is not possible a priori to separate contaminated and uncontaminated soils at the time of sampling. The best that can be done in this situation is to assume the data comprise several overlapping log-normal populations. A plot of % cumulative frequency versus concentration (either arithmetic or log-transformed values) on probability paper produces a straight line for a normal or log-normal population. Overlapping populations plot as intersecting lines. These are called broken line plots and Tennant and White (1959) and Sinclair (1974) have explained how these composite curves may be partitioned so as to separate out the background population and then estimate its mean and standard deviation. Davies (1983) has applied the technique to soils in England and ~~Wales and~~ thereby estimated the upper limits for lead content in uncontaminated soils. In the author's experience a degree of subjectivity is involved in the interpretation and ofetn plots are not readily partitioned.

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It should not be assumed that anomalous concentrations necessarily indicate contamination. Bolviken and Lag (1977) have described areas in Norway where the absence of vegetation is due to the toxic effects of high concentrations of metals in soils as a result of weathering of sulphide ores close to the surface. This is a natural process having nothing to do with contamination.

Identification of a geochemical anomaly should, in the first instance, be considered as only that, an anomaly. Other evidence must be taken into account to decide whether the anomaly is natural or is a neoanomaly, one caused by anthropogenic contamination.

D. THE PROCESSES AND PATTERNS OF LEAD CONTAMINATION

Lead contamination is a consequence of human use of the metal and its compounds. When these are heated, dissolved or pulverised they become labile and liable to escape to the environment. Having escaped they follow normal environmental pathways until they reach a geochemical sink such as soil or sediment. Valuable inferences may be drawn from the spatial distribution of lead concentrations.

Contaminating sources are generally classed as point or line. A smelter stack is a typical point source and highways are typical line sources due to the movement of motor vehicles and their exhaust emissions along them. A cluster of point sources forms an area source. But whatever the geometry of the source as contaminants are caried away they become diluted. Fallout from a stack tends to decline exponentially away fro the source. Overbank inundation in river systems leads to greatest contamination nearest to the river channel. Distinctive depositional patterns are thereby created and much can be inferred about the presence and nature of contamination by studying these patterns. Cartographical interpretation of data is an essential component of many contamination projects.

E. CARTOGRAPHICAL REPRESENTATION OF DATA

Many ways are possible for representing the spatial distribution of lead data ranging from sized or coloured symbols based on the relative concentration at the sample locality to complex statistical surfaces such as trend surface plots. But whatever style of representation is chosen an essential step in the data reduction is the manner in which the concentration values are classified to produce a relatively few groupings of the data from the minimum to the maximum. This can be done quite empirically by allocating class limits from experience. But this approach involves too high a degree of subjectivity.

The simplest systematic approach is to divide the range by, say, 10. Each metal value may then be allocated to its relevant

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Davies?

class and mapped. This was the method chosen by Davies (1973) for his subroutine PLOT which prints contour maps using symbols and a line printer. But skewed data again present problems. For the data in Table 16. the range is approximately 10,000 giving a class interval of 1000. But only 4 samples contain >1000 mg Pb/kg soil. here again, a log transformation improves matters. For the same data the class interval is (log) 0.3: the lowest class contains 1 value as does the highest and the data are regularly distributed through the classes.

A more laborious but more informative approach is through the frequency distribution of the data. The log-transformed values are classified (a class width of 0.1 is often suitable) and the percentage frequency in each class is calculated. These are then summed to 100%. A plot of concentration versus cumulative percent frequency is constructed and a smooth, sigmoid curve is interpolated between the points. This curve is then used to estimate the concentrations corresponding to selected percentiles. For contamination studies it is often convenient to use the 50, 60, 70, 80, 90 and 95th. percentiles. Ideally, the 50th percentile, the median and the geometric mean should be the same but irregularities in the frequencies combined with a best-fit of the curve often produce small discrepancies. Here, the 50th percentile corresponds to 40 mg Pb/kg soil compared with the geometric mean of 66 mg/kg and a median of 52 mg/kg. The 95th. percentile equates to 450 mg Pb/kg whereas the 95% upper probability limit was quoted above as 577 mg/kg (the 97th. percentile).

Broadly, there are two kinds of map. Where it cannot be assumed that there is any progressive change across a given area for the value of the parameter under investigation chloropleth maps are constructed. Areas of equal value are separated by boundaries from adjacent areas of different values. Familiar examples are soil or geology maps. But where progressive change can be assumed then isoline maps are used. Examples are topographical maps where contours connect points of equal elevation or weather maps where isobars connect points of equal atmospheric pressure. The familiarity of topographical maps compared with other isoline maps has often led to all isoline maps being loosely described as 'contour'.

It is dubious whether all geochemical data are properly representable by isoline maps. Since chemical composition depends on rock type and rock type can be depicted properly only by chloropleth maps then isoline maps are not generally suitable for geochemical data. But although soil composition is strongly influenced by parent material composition other processes are also significant, such as wind or water transportation of particles and compounds. Transportation over distance entails progressive change in deposition and therefore progressive change in soil composition. It has already been observed that the contamination effect is subject to a diminution away from the

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Table 17

Map isopleth values for lead derived from percentiles of a cumulative percent frequency distribution of the log transformed data.

Percentile9	mg Pb/kg soil
501	40
601	50
701	70
801	100
901	200
951	450

line or point source. It is reasonable to conclude that isoline maps are suitable for the study of lead contamination.

A number of computer program packages are now available for constructing isoline maps. Davies and Roberts (1978) and Davies and Wixson (1985) used the SYMAP system where isoline maps are printed on a line printer: in the papers cited these plots were redrawn for publication. There are major mainframe computer packages which produce very high quality monochrome or colour plots with inkjet or thermal printers. When using a PC microcomputer and a dot matrix printer the SURFER system of Golden Software, Inc., Golden, Colorado, is suitable.

Whichever system is used there is an important first stage. The data are imported into the program as X, Y and Z values (two geographic coordinates and the lead concentration) and from these a uniform grid of values is created. This entails extrapolation between neighbouring values to calculate the concentration at the grid intersection. The most common involves searching over a defined radius around each sample point and averaging using a weighting factor dependent on the inverse square of the distance between points. Another method depends on a moving average system called kriging (Davis, 1973). Since production of a regular grid is an essential preliminary then the more the distribution of the original data departs from regularity the more possibility there is of distortion of the eventual geographic pattern and the higher the likelihood of misinterpreting the pattern. Where the terrain permits it is much better to sample on a grid basis rather than rely on the chosen computer algorithm to regularise the grid.

Finally, the packages which are used to generate isoline plots will generally also print perspective block diagrams. These three dimensional figures are most helpful in interpreting geographic patterns.

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